

**H**AWAII  
**E**NERGY  
**R**ESOURCE  
**O**VERVIEWS



volume

**7**

**G**EOTHE**R**MAL

**S**UMMARY

B. Z. SIEGEL

## OVERVIEWS OF GEOTHERMAL DEVELOPMENT IN HAWAII

### VOLUME 1

Potential Noise Issues with Geothermal Development in Hawaii

John C. Burgess, Professor of Mechanical Engineering, University of Hawaii

### VOLUME 2

The Impact of Geothermal Development on the Geology and Hydrology of the Hawaiian Islands

Carol Feldman, Department of Oceanography and

B. Z. Siegel, Professor Pacific Biomedical Research Center, University of Hawaii

### VOLUME 3

The Hawaiian Ecosystem and its Environmental Determinants with Particular Emphasis on Promising areas for Geothermal Development

S. M. Siegel, Chairman and Professor of Botany, University of Hawaii

### VOLUME 4

The Impact of Geothermal Resource Development In Hawaii (Including Air and Water Quality)

S. M. Siegel, Chairman and Professor of Botany and

B. Z. Siegel, Professor, Pacific Biomedical Research Center of the University of Hawaii

### VOLUME 5

The Social and Economic Impacts of Geothermal Development in Hawaii

Penelope Canan, Associate Professor of Sociology and Pacific and Urban Studies at the University of Hawaii

### VOLUME 6

Property Rights to Geothermal Resources in Hawaii

Robert M. Kamins, Emeritus Professor of Economics from the University of Hawaii, and Attorney at Law

### VOLUME 7

The Impact of Geothermal Development on the State of Hawaii ---  
An Executive Summary

B. Z. Siegel, Professor, Pacific Biomedical Research Center and Director, Office of Research Administration, University of Hawaii





THE IMPACT OF GEOTHERMAL DEVELOPMENT ON THE STATE OF HAWAII

EXECUTIVE SUMMARY

by

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## TABLE OF CONTENTS

Executive Summary Introduction	1
Areas of Special Concern	2
Recommendations	6
Rationale for Specific Concerns and Recommendations	8
Legal Issues	8
Social Observations and Concerns	9
Geologic History and Its Impact	12
Climate	15
Vegetation Patterns	18
Environmental Consequences of Natural Processes in a Volcanic-fumarolic Region	24
HGP-A as a Site-Specific Model	30
Geothermal Resource Potential of Hawaii	35
Environmental Scale-Up	38
Workshop Reports and Special Reports	40
Broad Issues of Hawaii's Geothermal Development - Jack Keppeler	51
Political, Environmental and Human Concerns of Geothermal Development - Jeremy Harris	53
Hawaii's Endangered Species and Geothermal Development - Charles Lamoureux	55
Solutions Available to Hawaii to Solve her Energy Needs - Paul Yuen	62
County of Hawaii's Energy Self-sufficiency Program - Y. Hahn	66
Geothermal and the Electric Company - Dan Williamson	67
The Impact of Geothermal Development on the Local Geology - Tom Casadevall	68

The Impact of Geothermal Development on the National Parks of Hawaii - David Ames	71
The Impact of Geothermal Development on the Ocean's Beaches, Flora and Fauna, etc. - Keith Chave	74
The State of the Art in Geothermal Development- Engineering Considerations - William Chen	76
The State of the Art in Geothermal Development- The Gases and Effluents - Don Thomas	81
Summaries of the Geological Issues - Joseph Halbig	87



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## EXECUTIVE SUMMARY

Many of the questions regarding the sociological, legal, environmental and geological concern can be satisfactorily answered, at least with regard to Hawaii's sole well in Puna. Major social changes, environmental degradation, legal and economic constraints, seismicity, subsidence, changes in volcanic activity, accidents, and ground water contamination do not seem to be major problems at this time and with the present state of development. However, site-specific studies must be incorporated in all subsequent geothermal investigations at other potential sites, since a single small intermittently operating well does not provide sufficient data for wide extrapolation. Furthermore the social and physical environment is so unique in Hawaii that new words are often required to describe its characteristics (e.g., the "aloha spirit", "the ohana working together", the fields of "aa" and "pahoehoe", the "damn mainland haoles" who do not know that they are "malihinis" and pretend at being "kamaaina" etc.) In fact much of Hawaii's richness in flora, fauna, rare geological formations and life styles is barely understood, or even described. Therefore, much background and description have gone into preparing our concerns and recommendations so that we can convince the readers of the fragile and ephemeral modes of existence - plant, animal, rock and human spirit - which exist here in our Island Paradise.

This is not to say the the very rich geothermal potential which lies under our feet should not be developed, for the need for energy becomes more insistent each day, but rather that geothermal development in Hawaii must proceed with planning, deliberation, community involvement, and with an awareness of all the costs and all the benefits.



Many questions concern changes that can only be assessed with time. Continued and long-duration testing of the existing well is needed, not just for environmental and social impact assessment, but for reservoir engineering and development plans as well. But it must be stressed that the limited data available can hardly be extrapolated to a large generating facility with numerous wells, heavy production, and long periods of operations; nor can the information gained in Puna from only one well be readily applied to other potential geothermal sites in the State.

We have garnered these concerns and recommendations from several workshops and many meetings we have attended. We attempted to contact as many concerned citizens as possible -- students from high schools, home-makers, scientists, political figures, social leaders, farmers, developers, retirees, shop keepers and itinerant laborers. Their opinions, ideas and information have all gone into preparing these reports.

AREAS OF SPECIAL CONCERN


- \* Land ownership and geothermal rights in Hawaii are a volatile arena in which tourist-oriented businesses and their employees, banks and financial investors, the construction industry, real estate developers, agribusiness, and native-rights hui (associations) are often in conflict.
- \* Hawaii has pluralistic lifestyles which are the result of ethnic diversity and an uneven distribution of population and economic activity. Current geothermal resources on the island of Hawaii lie within a highly rural setting, whereas the city of Honolulu, the state's population center on the island of Oahu, dominates social, economic and political climate of the State.
- \* Because of single-wall construction used in building homes in Hawaii, noises from a geothermal source will have similar intensities indoors and outside. The nearest residences exist in the range of 4000-5000 feet from the present well, and it is likely that about one in every 10 people will become irritated by the noise at this distance. Residences and future well-sites will be in approximately the same range from each other.
- \* Subsidence due to removal of geothermal fluids is not considered a problem, but the collapse of lava tubes due to altered seismicity or water table modification is of major concern. However, the self-supporting nature of the rocks in the region of fluid withdrawal and the high rate of water recharge would indicate that there is little geological evidence in Hawaii to support these concerns, largely based on wells in California and New Zealand.

- \* Accidents caused by geological events, such as lava flows or earthquakes, which would drastically change the operation of a geothermal facility are of concern to near-by residents and farmers.
- \* Because of the high natural environmental baselines, any major additions of  $\text{SO}_2$ ,  $\text{H}_2\text{S}$ , mercury or arsenic must be carefully monitored locally and regionally during any geothermal development. The one extant well, HGP-A, causes little or no deterioration of the ambient air or water (while scrubbers are operational); but extrapolation of performance data from a single well must be approached cautiously.
- \* Hawaii has more unique endemic species than any other state -- approximately 2000. Extreme care must be taken in geothermal site selection and assurances must be provided that no degradation of unique habitats will occur.
- \* Most studies of Hawaiian ecosystems assume, or at least imply, that colonization and persistence in the face of volcanism have shaped a biota resistant to or tolerant of natural geothermal processes, effluents, etc., hence to man-initiated geothermal development. Objectively however we do not know a) how much selection for resistance to hydrogen sulfide and other effluents and b) how far into the post-volcanic period of an island such resistance factor, if present, can persist.
- \* Although the amount of radioactivity released by HGP-A operations from the Kapoho reservoir probably falls below hazardous levels in




open-air conditions, there are two situations not adequately examined with respect to radon in geothermal effluents: a) will radon daughter radionuclides accumulate in confined spaces in hazardous amounts and b) can radionuclides be introduced into the food chain in hazardous amounts by uptake and concentration in plants.


### RECOMMENDATIONS




Residents and developers would be protected from the effects of excessive noises which might result from geothermal development if the State of Hawaii or Hawaii County were to place appropriate noise regulations into effect prior to initiation of design efforts.



Definitive data in existing ambient sound levels in potential geothermal areas, as well as sound levels and spectral characteristics of all sound sources are needed before community impact and community response can be assessed.



Seismicity, subsidence, changes in volcanic activity, accidents, and groundwater contamination do not seem to be major problems at the present state of development. However, site-specific geologic and hydrologic studies must be incorporated into geothermal investigations at other potential sites. Better microseismic coverage and information on subsurface geology are needed outside of Puna. Lava tubes are poorly understood but are frequently presented as potential "troublemakers".



The pattern of extraction of geothermal resources and their pricing may well differ between private and public ownership. Furthermore the experience of the petroleum industry has documented the wastefulness of the mode of competitive drilling, which results in a smaller total recovery of the resource available than does "unitized" exploitation of each reservoir. Currently, Hawaii law provides for unitization in the exploitation of geothermal fields but does not require it. Government intervention in pricing may be necessary to

distribute the economic benefits of geothermal energy development more broadly than merely among the owners, extractors and appliers of heart.



In addition to continued monitoring of HGP-A, each new prospect for geothermal development should be subject to baseline bio-ecological and physical-chemical analyses of sulfur, metals, etc., prior to the initiations of drilling procedures. Subsequently, any well successfully brought in and any direct use or generating facility developed from it should be closely monitored for a period of years.

The general belief that Hawaiian organisms are adapted to volcanic environments requires verification and should be the subject of field and laboratory analysis and experimentation.

More extensive radiochemistry of the Kapoho reservoir is needed and should be followed by experimental study of plant uptake of radon daughter nuclei at levels corresponding to geothermal effluent release.



Many questions concern changes that can only be assessed with time. Continued and longer-lasting tests of the existing well are desirable, not just for environmental impact assessment, but for reservoir engineering and development plans as well. The limited data available can hardly be extrapolated to a large generating facility with numerous wells, heavy production, and a long period of operation; nor can information gained in Puna be readily applied to the other potential geothermal sites in the State.



RATIONALE FOR SPECIFIC CONCERNS AND RECOMMENDATIONSSUMMARY OF LEGAL HISTORY AND ISSUES REGARDING GEOTHERMAL RIGHTS

A sharp discontinuity in the administration of Hawaii's unique land laws has created uncertainty as to the ownership of geothermal resources in the State. Until Hawaii was annexed to the United States and governed under the Organic Act of 1900, mineral rights had with rare exception been reserved to the government, even though the statutory requirement for making the reservation had been repealed in 1859. Beginning in 1900 and through 1955, the practice was reversed and lands were patented without mineral reservations -- even some lands which had originally been granted subject to a reservation. Further, the Land Court created by the Territory issued certificates of titles to lands registered under the Torrens system omitting mineral reservations made at the time of original conveyance by the government. It is unclear whether reservations are to be implied in some or all of the titles issued without express reservation clauses.

The uncertainty is compounded by contradictory arguments which can be readily made as to whether "mineral" reservations in Hawaii encompassed geothermal resources in grants made prior to a 1974 statute which states that they do. The cryptic history of mineral reservations in a jurisdiction lacking minerals in the usual sense of the term is uninformative as to the intent of the Kingdom, Provisional Government and Republic which made the reservations. Case law in Hawaii is limited to a single relevant decision which is not dispositive of the question, nor are rulings in other portions of the Ninth Circuit regarding geothermal rights.

In the absence of a clear statutory rationale or authoritative case law, a court may well be influenced by considerations of social policy, notably whether Hawaii common law has adopted a public interest

doctrine which applies to geothermal resources, and whether these resources come under a public lands trust in favor of the Hawaiian people, as asserted by an advocate for one association of Hawaiians. In this context, the Hawaii Supreme Court has recently show a receptivity to social policy arguments, while in parallel cases regarding ownership of natural resources, the Federal District Court in Hawaii has been more protective of private property rights under the 14th amendment.

#### A SUMMARY OF SOCIAL OBSERVATIONS AND CONCERNS

Hawaii is almost totally dependent on outside sources of materials, including energy supplies, yet she abounds in natural energy sources. Geothermal is only one of several alternate energy sources which make Hawaii a model for developing renewable energy models; the State abounds in ocean thermal (OTEC) potentials, has high and continuous winds, intense sun light for solar and biomass development, and an agribusiness that already supplies 30-50% of the electricity on some of the Hawaiian islands just be burning sugar cane waste. This Overview of social and economic issues is part of the attempt to broaden the decision base for smooth transition to a natural energy future. Since uncertainty abounds in alternate energy development, social equity and political sensitivity are important issues in energy development.

Since there is little consensus on the content of a social impact assessment, it behooves concerned parties to reach agreement on its form, purpose and manner of procedure; the five basic steps for assessing social impact are

- profiling
- projecting
- assessing
- evaluating
- recommending

Social effects are part of the "objective future"; social impacts include the subjective definitions attached to them. Therefore, social impact assessment is a highly political venture and to reduce the bias, an interdisciplinary teach approach is ideal. In all of this, the public has a right to partnership in assessing social impacts.

Hawaii in profile shows no single energy grid, and each island is unique and the impacts of any technological development would be variable. Land ownership is extremely concentrated and a volatile arena and the control of local economic conditions by outside interests is extensive and growing. The sense of vulnerability parallels historical evidence of "colonialization". Population pressures add further stress to a very finite land area. And pluralistic lifestyles abound as a result of ethnic diversity and uneven distribution of population and economic activity.

The economy is dependent on four major industries - tourism, defense, pineapple and sugar. The cost of living is approximately 25% higher than found among major mainland American cities. The city of Honolulu dominates the social, economic and political climate of the State. None the less, the local government is the most streamlined and centralized of all American states. The energy policy at the State level has been defined as supportive of private commercialization. The direction of the State's desired development appears to be large-scale technological solutions to the State's energy dependency. Geothermal is a prized alternate energy source for Hawaii.

One of the lessons we have learned from the single well at Puna is that the negative aspects will be localized. People in the vicinity of the test well appear united in their disapproval of development projects

aimed at exporting energy from the region. They would prefer assurances that the State will equally encourage direct applications that would diversify the local economy The right of the community residents to be involved in determining their future environment should be emphasized and truly facilitated. The extent of development hinges on the trade-off between local, regional/island, and State benefits.

The population and economic considerations are the most important in predicting the future social effects of a specific development. The reduction in physical beauty of any community in which a geothermal plant is located is of major concern to the citizens of Hawaii, and is a deep value found on all the islands. Therefore, micro-energy solutions may be more appropriate for islands with limited energy demands, and geothermal energy is especially attractive for diversifying the local economy given the possibility of using hot water in sequential applications. The lack of an inter-island energy grid contributes to the wisdom of decentralized geothermal development.

In recent history there has been a negative correlation between energy consumption and the "quality of life". Efforts to substitute natural energy sources to support present consumption patterns may be unnecessary and undesired. Citizens should be involved in energy production and consumption policy decisions, and social impact assessments as a process can involve the public and thereby contribute to the quality of life.



## ORIGIN OF HAWAIIAN ISLANDS

The geologic history of the Hawaiian Islands can be understood in terms of a series of volcanic episodes spanning tens of millions of years and extending along a stupendous fracture zone cross the mid-Pacific ocean floor for at least 1500 miles. The earlier parts of this story are observed in submerged and buried layers of lava which have long since been recycled through the surfaces of lava domes along the rift. Many such domes exist along this line; at least 26 of them appear above the present surface of the sea forming the islands, the Hawaiian Archipelago.

## GEOBIOLOGY

The substrata for vegetation are the basaltic lavas and ash from the volcanoes, and soil derived from the weathering and disintegration of this basalt. Locally there is also the limestone of the elevated coral reefs and coral sand flats that surround the older islands or even make up their entire surface. Every degree of weathering may be seen and some deep old soils exist.

The principal Hawaiian Great Soil Groups are as follows:

- |                            |                                  |
|----------------------------|----------------------------------|
| 1. Dark Magnesium Clays    | 8. Ferruginous Latosols          |
| 2. Gray Hydromorphic Soils | 9. Aluminous Ferruginous Latosol |
| 3. Clays                   | 10. Humic Latosol                |
| 4. Paddy Soils             | 11. Laterite                     |
| 5. Red Desert              | 12. Tropical Reddish Prairie     |
| 6. Reddish Prairie         | 13. Latosol Brown Forest         |
| 7. Low Humic Latosol       | 14. Hydrol Humic Latosol         |

Although geothermal development is projected for all the Hawaiian Islands, the active volcanic region in and around Kilauea, where the current Hawaii Geothermal Project well is located, is unique. This area presents a series of engineering challenges and public concerns. From a purely environmental perspective, questions of geothermal development

may find ready answers in the moderately extensive studies conducted on volcanic activity and its impact on the environment.

ISLAND OF HAWAII: This is the only island with proven geothermal resources. A 3-5 megawatt (electrical) well is expected to be in operation by 1981. Hawaii has been the major object of these environmental studies. The largest, highest, youngest, and most complex of the Islands exhibits a corresponding environmental diversity. Altitudinal zonation occurs from sea level to well above timber line; climatic variation from orographic rainy regions and soaking bogs to desert rain shadows; and a complete range of primary ecological successional stages from fresh lava to rain forest on deep ancient soil.

The Island of Hawaii is one of the eight major islands of the State. It has an area of about 10,500 km<sup>2</sup> (2,579,000 acres or ca 4,030 sq. mi.). Although its land area is 62.7 percent of the State, its population of 65,941 is only 8 percent. Hilo, the county seat, is about 216 miles southeast of Honolulu, the State capital.

Farming is the main source of income, and the highly mechanized production of sugarcane has been the main industry. Farming is now diversified, however, and other enterprises, including the production of macadamia nuts, papaya, truck crops and one of the most extensive orchid cultures in the world are increasing rapidly as are anthuriums and ornamental foliage. The only coffee grown in the United States is produced in the Kona district. The island leads the State in the production of cattle. Parker Ranch, the second largest in the United States, is in the Kohala District. Tourism also is a growing source of income.

The Island of Hawaii is commonly called the "Volcano Isle," the "Orchid Isle," or the "Big Island". It has the only active volcanoes and the largest land mass in the State.

ISLAND OF MAUI: This island has potential geothermal areas, but much exploration is still required. It consists of two high volcanic domes connected by a very low isthmus. West Maui is much older and more deeply eroded of the two, and is only 1762 m high. There has been no volcanic activity since late Pleistocene. East Maui, or Haleakala, on the other hand, reaches 3139 m and has been the site of lava flows probably as late as 1750. It still shows large exposures of scarcely or slightly weathered lava and ash. Its upper parts extend above the level of trade wind rain and on its leeward south slopes the rain-shadow effect is strongly developed.

ISLAND OF OAHU: Oahu has two potential geothermal sites identified and is third largest of the Hawaiian Islands, made up of two old volcanic domes, both apparently down-faulted on their seaward sides, leaving tremendous cliffs facing the sea and gentler slopes toward the depression that separates them. These domes take the form of two roughly parallel mountain ranges, the Waianae Range on the west side, the Koolau Range on the east, trending northwest-southeast.

ISLAND OF KAUAI: Kauai is principally a single enormous, deeply dissected volcanic dome with no geothermal potential identified and has gently sloping land on the lower slopes. Its highest peak, Waialeale, 1576 m, does not reach high enough to be above the orographic rainfall levels, and receives an enormous precipitation.

CLIMATE

The Islands lie entirely within the trade wind belt. The northeast trades, moisture laden after a long sweep across the Pacific, hit the mountainous islands, rise forming rain clouds and continually drench the windward slopes and crests with heavy "orographic" rainfall. Convection also influences the rainfall pattern on the very high islands. Certain areas on the lee sides, where normally extreme aridity would be expected, receive afternoon rains as a result of the rise of air warmed by the sun.

Hawaii is the only state which lies within the tropics, and is composed of relatively small islands completely surrounded by ocean. These facts contribute to its unique climate. Almost half the land in the state lies within 8 km (5 mi.) of the coast. Only about 5 percent, all on the island of Hawaii, is more than 33 km inland. Thus the marine influence on the climate is pronounced.

The northeast tradewinds account for dominant air movements over the state, and rainfall distribution is influenced primarily by the trades and the terrain. From May through September the trades are prevalent 80 to 95 percent of the time, but from October through April only 50 to 80 percent of the time. Average annual rainfall of the state is about 180 cm (70 inches), but great variation from place to place makes this figure meaningless.

Seven climatic subregions are recognized. These are defined chiefly by the major physiographic features of the State and by location with reference to windward or leeward exposure. "(1) WINDWARD LOWLANDS, generally below 700 m on the north to northeast sides of the islands; (2) LEEWARD LOWLANDS, except for the Kona Coast of Hawaii



which has a distinctive climate; (3) INTERIOR LOWLANDS, on Oahu and Maui. In the northeast these lowlands have the character of windward lowlands and the southwest of leeward lowlands; (4) THE KONA COAST OF HAWAII. This is the only region in which summer rainfall exceeds that in winter; (5) RAINY MOUNTAIN SLOPES ON THE WINDWARD SIDE. Rainfall and cloudiness are very high, with considerable rain both winter and summer; (6) LOWER MOUNTAIN SLOPES ON LEEWARD SIDE. Rainfall is greater than on the adjacent leeward lowlands, but distinctly less than at the same level on the windward side; (7) HIGH MOUNTAINS. Above 700-1000 m on the high mountains of Mauna Kea, Mauna Loa, and Haleakala rainfall decreases rapidly with elevation."

#### PLANTS AND ANIMALS

The first problem in reconstructing the history of Hawaiian life is to explain the presence and nature of plants in such remote and isolated islands. The first land available for colonization must have been an unstable mound of volcanic material, ash, or perhaps lava, somewhere in the western end of the Hawaiian chain in the neighborhood of the present Kure and Midway Islands. One successful establishment of a new organism every 20,000 to 30,000 years would be sufficient to account for the present array of species. As plants became established on the new substrata there was nothing to impede their multiplication until all the suitable ground was covered. Evolution was encouraged both by isolation and by periodic catastrophic reduction in population and size. Under conditions of reduced competition, and from a limited assortment of original types, evolution would also be expected to produce curious growth forms with characteristics not commonly found in certain plant groups. The progeny of the few stocks present would occupy niches ordinarily held by members of other families.

The lack of grazing animals was also a factor in the survival of many unusual forms of plant life, but with the arrival of early man, who brought with him the pig, there also appeared an assortment of useful plants and probably weeds. The effect on the vegetation must have been drastic, locally at least. Vegetation in favorable sites was destroyed to make way for agriculture and for trails and villages. After hundreds of years of occupation by the Polynesians certain equilibria between man's activities and the vegetation may have come about. Fairly stable patterns, different in some areas from earlier ones, may have evolved.

When European man arrived, he brought cattle, goats, sheep, other domestic mammals, new agricultural plants, and new methods for their culture. Now almost all the vegetation types that are commonly seen excepting certain of those on new lava and ash around Kilauea Volcano, are composed largely or entirely of non-Hawaiian plants.

One biological consequence of recent geological age is that tropical island rain forests on high volcanic islands are much younger than most tropical continental forests. In certain areas in the oldest parts of the high Hawaiian Islands it is estimated to be six million years old. Only one arrival form was required to become successfully established every 20,000 to 30,000 years to account for today's native angiosperm flora of a little over 1,700 taxa. The shorter geological time available for community development may in part account for a lower diversity in tropical island as compared to tropical mainland communities.

Because of unique evolution and species assemblages, the structure of island communities is expected to be unique also. There are grasslands, bogs, alpine tundras, savannas, closed evergreen rain

forests, open seasonal forests, scrub formations, and deserts, to name a few of the more common biomes. These are conditioned by the peculiarities of climates and soils just as they are on continents.

#### VEGETATION PATTERNS

METROSIDEROS FOREST: As broad-leaved evergreen forest usually dominated by trees of the genus Metrosideros, the ohia lehua of the Hawaiian Islands.

CLOUD FOREST: Above the Metrosideros belt, on many of the mountains of the Hawaiian Islands, there is a cloud forest zone of mixed evergreen forest. It is characterized by gnarled, spreading, much-branched trees, abundance of shrubs and masses of epiphytic mosses, hepatics, ferns and vascular forms.

BOGS: In high, very rainy regions, especially on flat or gently sloping ground, true bogs are found.

METROSIDEROS WOODLAND WITH GLEICHENIA: On the moister aspects of the Island of Hawaii, especially on relatively young lava flows, occurs a vegetation composed of thick, more or less continuous, blanket of Gleichenia linearis var. tomentosa with widely spaced Metrosideros trees.

MIXED MESOPHYTIC FOREST: In areas less wet than the rain forests but not suffering an actual moisture deficit, and usually where the lavas have been well weathered, are evergreen or partially deciduous sclerophyllous to orthophyllous forests of diverse composition.

ACACIA KOA FOREST: The best known of Hawaiian trees is the koa, sometimes called Hawaiian mahogany.

ALEURITES FOREST: In gulches and along stream courses at moderate to low altitudes, Aleurites moluccana (kukui) forms dense stands.



PSIDIUM GUAJAVA FOREST AND SCRUB: One of the commonest vegetation types in moist to wet areas at moderate to low elevations in the islands is a dense solid stand of the guava, introduced many years ago for its edible fruits and scattered by birds and pigs.

PSIDIUM CATTLEIANUM FOREST: In many wet or mist areas, especially in koa, lehua, and mixed lowland forest, Psidium cattleianum (strawberry guava), or in places, a related species, P. littorale (waiwi), has gained a foothold or been planted.

LANTANA SCRUB: A widespread scrub formation, found on all the large islands, especially in areas that are neither excessively rainy nor excessively dry, is made up of solid stands of Lantana camara of tropical American origin.

LEUCAENA SCRUB: In rather dry to moderately wet areas at low to middle altitudes, especially in disturbed places, roadsides, abandoned fields, and dry slopes, in former koa forest, dry sclerophyll and mixed lowland forests, Leucaena leucocephala (usually incorrectly L. glauca) forms dense solid stands, usually 2-4 m tall.

PASTURES: Artificial pastures in Hawaii are very diverse in species composition and somewhat diverse even in structure. Under the term pasture are here included those areas where the native vegetation has been largely removed and replaced by herbaceous cover, principally of grasses but often with a considerable admixture of leguminous and other broadleaf herbs.

PLANTED FORESTS: The islands also contain various types of planted forests. Frequently they are blocks composed of single species, especially Eucalyptus robusta, Melaleuca quinquenodia, Grevillea robusta, Acacia dealbata, Cupressus macrocarpa, Araucaria excelsa, and other conifers.



MIXED LOWLAND FOREST: Along wet lower slopes and in the mouths of all but the drier valleys there existed a moist mesophytic forest which has been mostly destroyed or so altered that its original composition is now quite uncertain.

DRYLAND SCLEROPHYLL FOREST: Large areas of dry coastal slopes and higher rain shadows, probably most of the relatively dry areas below 1500 m, were originally covered by an open scrub forest, principally of broad sclerophyll trees.

PROSOPIS FOREST: In dry lowland areas around all the larger islands is a forest of Prosopis pallida (keawe). This leguminous tree is related to the mesquite of northern Mexico and southwestern United States.

HETEROPOGON GRASSLAND: On steep dry leeward lower slopes and cliffs, especially on truncated lava spurs where the soil is thin, are grassy areas long free of forest.

OPUNTIA SCRUB: On many leeward, dry areas, usually at rather low elevations, the vegetation is dominated by Opuntia megacantha. This huge swollen, spiny plant forms dense thickets up to 3-4 m high, mixed with Lantana, Acacia, Prosopis and other xerophytic shrubs, as well as Heteropogon contortus and various dry land weeds.

WET CLIFFS: Along the windward sides of the islands, and even on leeward exposures in certain deep amphitheater-headed valleys, are great fluted wet basalt cliffs, up to a thousand meters in height, with almost no soil and little vegetation.

DRY CLIFFS: Even less is known of the vegetation of dry basalt cliffs, such as exist on the Waianae side of Oahu, on valley walls of southeast Oahu, the windward side of Lanai, around Haleakala "Crater", and in various other locations in the rain shadows.

STRAND: The strand -- the shoreline and the zone immediately back of it that is strongly influenced by the sea -- has in many parts of the Hawaiian Islands been so completely disturbed that it is hard to tell what it was originally like, yet elsewhere has preserved its physiognomy and even its native species.

MANGROVE SWAMPS: Mangrove swamps were lacking in the Hawaiian Islands prior to this century. After several species of Rhizophoraceae were introduced they rapidly spread into favorable habitats, and swamps developed at a number of places, especially at Heeia, Oahu and west of Kaunakakai, on the south coast of Molokai, where they filled fish ponds and occupied shallow muddy places.

FAUNA: The fact that the Hawaiian Archipelago is isolated by open ocean is the most important factor in the development of prehistoric animal life. Birds constituted the principal early immigrants, hence it is significant that the only unquestionably native mammal is the Hawaiian bat (Lasiurus semotus).

Ancient bird life originated from many points of the compass. The ancestors of the honey creepers probably arrived from South American, and the honey eaters are similar to those found in Australia and New Zealand. A later arrival, the predecessor of the present species of flycatcher, is also considered Australian in origin. The thrushes seem most closely related to Polynesian, Melanesian, and Malaysian species. The non-migratory goose (Branta sandvicensis) and duck (Anas platyrhynchos wyvilliana) closely resemble the Canada Goose and Mallard in structure. The subspecific coot (Fulica americana alai) and gallinule (Gallinula chloropus sandvicensis) are similar to the North

American types. The distinct Hawaiian stilt (Himantopus himantopus knudseni) is most likely derived from an American ancestor. The sea birds, and owl (Asio flammeus sandwichensis) are sub-species of birds with world-wide distribution. The native crow (Corvus tropicus) is similar in appearance to the Australian crow. The hawk (Buteo solitarius) is considered closely related to the Swainson's hawk of North America.

The early Polynesian navigators brought with them domestic animals as well as food plants. The aboriginal jungle fowl, domesticated for years, soon went wild in the uninhabited forests. The pig reverted readily to a wild state. The larger domestic animals were brought in primarily as gifts for royalty by the first explorers.

Frogs and toads were introduced from Japan and America as early as 1867 by the Royal Agricultural Society. There are no snakes in Hawaii except for a small blind snake and of course various species of sea snakes.

Many birds were introduced for hunting, control of noxious insects, or esthetic reasons since the mid-19th century. The most common introduction is the Indian Mynah (Acridotheres tristis) which was introduced to control cutworms (1865).

Almost a hundred birds have been introduced from all over the world with varying degrees of success. This has had an undesirable effect on the native song birds, particularly the highly specialized honey creepers and honey eaters.

"Big game" animal introductions are a little more difficult to plan, as land use conflicts, disease, and availability often prohibit entry. However, the European Mouflon sheep (Ovis Musimon) and North

American prong horn (Antilocapra americana) have been successfully released recently on the island of Lanai and reproduction has occurred. The most successful large mammalian import to date is the Axis deer (Cervus axis).

Hawaii originally boasted one of the most unique faunas in the world. The advent of man agriculture, and changing land uses, caused these animals to become reduced in numbers, or even extinct. Through strict quarantine against disease, and research as to the effects of exotics on the existing wildlife, the prevention of further extinction of primitive forms is being effected.

As an example, the coastline of Oahu at Black Point consists of a basalt outcrop massive blocks fronting directly on the sea. The basalt blocks are interrupted by tidepools of varying size and small, rubble surfaced coves. The dominant faunal element of the spray zone are the molluscs.

The tidepools harbor a rich and varied fauna. Of the coelenterates, the sea anemones Marchanthea and Bunodactis occupy sandy bottoms and crevices respectively; and the "soft" coral, Zoanthus coats the sides of pools. The fish fauna of the tidepools is made up of a number of well known species. Istiblennius occurs in shoreward pools with the gobies Bathygobius and Kellogella. A less varied fauna is found on the exposed portions of the coastline.

Insects probably first reached the Hawaiian Islands soon after plants became established more than 10 million years ago. The changes must have taken place at a slow, leisurely rate to produce one of the most unusual faunistic assemblages present upon the face of the earth. But recently, changes have come more rapidly as man has set upon the



islands and turned the land to his own use. The effects upon the native plants and insects have been disastrous. They have been unable to withstand these changes -- both physical changes of the land and the competition from introduced organisms.

There are over 5000 species of insects in Hawaii. They are not representative of continental groups, but are random samples that were able to make the oceanic voyage and gain a foothold in the islands. Most of the native insects on Hawaii have originated in Tropical Asia. Zimmerman lists more than 90% of the genera with Pacific affinities. That the native insect fauna of over 3000 species could have developed from chance immigrants is emphasized by Zimmerman. He calculates that the majority of the native insects have been replaced by immigrants in the lowlands below about 2,000 feet.

#### THE ENVIRONMENTAL CONSEQUENCES OF NATURAL PROCESSES IN

##### A VOLCANIC-FUMAROLIC REGION

Both seismic and eruptive activities in volcanic zones can, at their extremes, lead to catastrophe. In themselves, devastating effects of volcanism are of little concern with respect to the environmental impact of forthcoming and future KGRA development in Hawaii. However, the development of geothermal power in regions of active volcanism does have significant impact on investment risks and engineering design.

The toxicity of volcanic effluents is recognized, and will be considered below. The release of  $H_2S$ ,  $SO_2$ ,  $SO_3$  ( $H_2SO_4$ ), hydrohalogens and mercury may be enhanced during eruptions over their normal output from fumaroles and vents.

For example, during the Kalalua eruption of September-October, 1977, the  $\text{SO}_2$  and  $\text{H}_2\text{S}$  levels 1 km downwind from the nearest vent rose more than 25-fold over their August values. The  $\text{H}_2\text{SO}_4$  concentration did not show a corresponding rise, but on other occasions, rainfall measuring pH 4.0 has been collected in Kona, some 75 km from the nearest vent.

Escalation of mercury during the 1977 eruption was better documented. Field measurements carried out prior to the event established firm baselines, permitting the conclusion that at various locations, the Hg level rose from less than 10 to over 400-fold.

One of the consequences of a long history of volcanism and eruptive events of varying duration and destructive force has been the selection of individuals, and eventually populations, capable of withstanding and/or recovering from severe injury. A second lies in the presence of populations capable of invading and establishing vegetation on the new surfaces left in the aftermath of an eruption. That this capability should be a common feature of many Hawaiian species is implicit in the colonization history of the islands themselves.

The appearance of a new active fissure is associated with elevated emission of toxic gases and their dissemination into areas which ordinarily contain only low levels of these toxicants. Periods of high mercury output occur frequently at fumaroles. Emissions along the Kilauea East Rift proximal to the main vent maintain high air mercury levels in the absence of overt eruptive activity. The Sulfur Bank 7-year mean level of  $\text{ca } 16 \text{ g}\cdot\text{m}^{-3}$  ( $4 \text{ g}\cdot\text{m}^{-3} \text{ Hg}^\circ$ ) represents an area at least  $300\text{--}400 \text{ km}^2$  in extent on the Kilauea plateau, based on a 10-12 km radius around the main vent. Even at greater distances, e.g.

the site of HGP-A, air mercury levels since 1975 during non-eruptive phases have ranged between 0.2 and 1.2  $\text{g}\cdot\text{m}^{-3}$ , fluctuating around  $1\mu\text{g}\cdot\text{m}^{-3}$ .

More recent measurements (1976-78) show abundant sulfur gases as well as mercury.

Sulfuric acid measurements have not been as extensive as those for other gases. In July-August 1977 the Sulfur Bank yielded air values of about 1  $\text{mg}\cdot\text{m}^{-3}$  and the Halemaumau vent 6.6  $\text{mg}\cdot\text{m}^{-3}$  under clear dry conditions, 1  $\text{mg}\cdot\text{m}^{-3}$  during heavy rain. Outside of these specific sites, values were 0.25  $\text{mg}\cdot\text{m}^{-3}$  and commonly less.

The long term health effects of these natural air mercury levels are not known, but it is clear that local resident populations are exposed to concentrations above recommended threshold. Little information exists pertaining to chronic mercury intoxication by inhalation in animals, although health standards might be applicable to some forms of mammalian life. Even less information is available about atmospheric exposures of plants.

The natural emission sources in Hawawii range from  $\text{H}_2\text{S}$  ambients of 0.002 to high values of 1.2-7.1 ppm (2 year average). These values offer no occupational hazard but the higher levels are far in excess of the California air quality standard and those of most other areas, both in and out of U.S. jurisdictions.

The Case of  $\text{SO}_2$ , with air values ranging from 0.02 ppm to high 2-year averages of 4-7 ppm and an extreme 3 m level of 21.2 ppm (1971 fissure), shows that even short term occupational health standards can be exceeded at natural sites, and Ambient Air Quality Standards readily and regularly.

Sulfuric acid levels rarely reached the occupational threshold limit value, but one case at the Kilauea vent in excess of the Short Term Limit was observed over a 1 hour interval.

There is little information concerning the direct effects of  $H_2S$  on individual plants, vegetation or ecosystems in general. However, levels of 0.03 ppm are commonplace, not only in marine and fresh sediments, but in swamp, marsh and bog environments in which many kinds of plants and soil microbiota flourish.

Since natural sources of sulfide have been a feature of the environments during the evolutionary process, the aqueous environment may contain species that are tolerant to low concentrations of sulfide.

In certain agricultural areas, the losses to growers resulting from sulfur dioxide injury are sufficient to be of economic importance, particularly in coniferous and eastern hardwood forests. Specific effects on tropical plants and ecosystems are largely unknown. Markings on vegetation caused by sulfur dioxide are usually found in areas adjacent or close to the source, but their positive identification with the presence of sulfur dioxide can be made only after all foliar symptoms and related evidence have been considered. These include: (1) the presence of suspected sources of sulfur dioxide; (2) the species of plants that develop markings; (3) the type of markings that are observed; (4) the pattern shown by the severity of the markings and locations of occurrence, i.e., most severe near the suspected source on species known to be sensitive and decreasing in severity with distance from that source.

In general, yields of crops are not affected unless chronic or acute markings have developed on the leaves. Results seem to show that



at least 5% of the leaf area must be destroyed before the crop yield (e.g. small grains) is significantly reduced. It is characteristic to find both chronic and acute type markings on many plant species following an exposure to sulfur dioxide. This is an important factor used to identify sulfur dioxide injury in the field as opposed to markings caused by other agents. Often both types of markings may appear on the same leaf.

Higher plants and commercial crops are generally 10-100 X more resistant to sulfur dioxide than lower forms.

Two-year ambient  $\text{SO}_2$  averages of 4-7 ppm at the E. Rift are well above the threshold toxicity values as defined in non-thermal areas outside of Hawaii. Large volcanic areas (at least 25 sq. km) in Hawaii are heavily covered with a lichen (Stereocaulon volcanii) and any changes in its coverage could have significant impact on water retention, erosion, etc.

The significance of acid rain in tropical ecosystems remains to be defined. Rainfall pH values and ionic composition data have been reported for the Saddle Road area between Mauna Loa and Mauna Kea at elevations up to ca 2000 m some two years after the Kilauea eruption of 1955. Below 1000 m samples averaged  $5.0 \pm 9.3$  and  $5.4 \pm 0.2$  at higher levels, which were also more distant from the ocean. The composition differed significantly from seawater, indicating contributions of volcanic  $\text{H}_2\text{SO}_4$  and  $\text{HCl}$  to Hawaiian rainfall. Reference has already been made above to even more acidic rainfall (pH 4.0) in Kona, some 75 km from Kilauea. This acid rain, also showed  $\text{SO}_4^{-2}$  and  $\text{Cl}^-$  enrichment.

South of the Halemaumau Caldera lies a vast desolation, perhaps 400 km<sup>2</sup> or more in area known as the Ka'u Desert. Its barrenness is striking because many similar areas are at least dotted with lichens, Boston fern and Ohia. The term "desert" in no way connotes xeric environment: the mean annual rainfall of about 1,200 mm, although highly seasonal, should support the sort of vegetation cover seen elsewhere in Hawaii. It is likely that the combined effects of H<sub>2</sub>S, SO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub> aerosol, mercury and perhaps other emanations from Halemaumau, carried by the prevailing winds, offer all of the constraint necessary to colonization.

The Hawaii Geothermal Project's environmental program was predicated on the concept that the toxicology of fluids brought to the surface by human activity could be anticipated from a knowledge of fumarolic and volcanic effluents. This was prompted by the demonstrations of high ambient air mercury levels around Hawaiian fumaroles. These concerns were not limited to mercury but also extended to other toxic elements to be found in other geothermal areas including arsenic, antimony, thallium, etc.

If no novel toxicants surface in geothermal effluents released by drilling, then qualitatively, at least, the local biota may well have been selected for resistance by exposure to fumarolic and volcanic emissions. This possibility, although reasonable in a formal sense, has not yet been subject to field or laboratory verification. The composition of fumarolic and volcanic gases reveals qualities of some constituents that probably exceed even the adaptive potential of rugged colonizers, at least in close proximity to sources.

Whatever uncertainties exist with respect to site and time relations for "built-in" resistance to hydrogeothermal effluents, they cannot be applied casually to the entire ecosystem and certainly not to Man and his introductions.

#### HGP-A AS A SITE-SPECIFIC MODEL

The Puna District, site of HGP-A, is the easternmost projection of the Island of Hawaii, comprising approximately one-eighth of its 10,500 km<sup>2</sup>. The District is formed by undissected volcanic uplands, and the Puna cone and crater area, marked by recent (1955) eruptions.

With an estimated mid-1978 population of 8,300, Puna is the second most populous of the nine districts of the Big Island.

Much of the area around the geothermal site is a suburban wilderness of empty subdivisions. In a few places, thin plumes of steam mark active vents. To the east, is a major papaya area and to the west, productive sugar lands.

The hydrology of the Puna District is not well established. The area appears to be underlain by a lens of basal water floating on salt, with a relatively narrow band of dike-confined water running across the southern part of the District, and with a coastal zone of brackish basal water to the west. Basaltic dikes may block off the fresh water lens from the geothermal reservoir.

Comparing the genera and species present with the most relevant lists of known rare, endangered and threatened genera and species, we conclude that if present at all at the well site, they are extremely infrequent.



It should be noted (1) that toxic emissions resulting from well operations are not likely to differ from those normal to natural vents and magmatic outgassing in Hawaii, and (2) that natural populations established by post-eruption colonization in areas of recent or current vulcanism may be more resistant to toxic geothermal emissions than would be the case in non-volcanic locations.

The only valued animals which might be disturbed or conceivably threatened by geothermal development in the District are birds. It is the considered opinion of the ornithologists who studied the area that the activities at the geothermal well site have had no adverse effect on any bird species inhabiting the area. Even an adverse effect on some of the introduced birds would not necessarily be detrimental, because some of these species have proven to be nuisances, or even harmful.

Puna has played a relatively insignificant role in the political history of Hawaii. Consequently, there are relatively few archaeological sites in Puna, in comparison with the Kona coast or the north-west corner of the Island of Hawaii, and there is no major site of archaeo-research interest in the District.

HGP-A Well Chemistry. The water quality sampling program of the HGP-A consisted of a series of five downhole water samplings at various depths under no-discharge condition, one similar sampling under very low discharge condition, and water quality monitoring of the discharge of the longest discharge test, March-May 1977.



WELL WATER QUALITY

pH	5
conductivity	3100 mho/cm
salinity	2.3%
chloride	925 mg/l
silica	420 mg/l
magnesium	1 mg/l
tritium	<0.2 T units
age	50 years

WELL CHARACTERISTICS

Temperature	358°C (676°F)
Steam (water vapor)	60-70%
Depth	1983 m (5851 ft)
	below sea level

Deep dikes or intrusive bodies located on the ocean side may act as barriers against sea water encroachment.

Mass balance calculations involving carbon, its isotopes  $C^{14}$  and water and  $O^{18}$  indicate that 10 percent of the water comes from the ocean, 66 percent from ground water and 24 percent from a hydrothermal source.

Aerometry at HGP-A dates back to May 1975. At no time have ambient levels of CO exceeded 1 ppm, even when heavy diesel-powered equipment was in use. Similarly,  $\text{NO}_x$  concentrations have not reached the 0.1 ppm level, nor would the low traffic density lead one to expect significant levels.

Both  $\text{SO}_2$  and  $\text{H}_2\text{S}$  were monitored starting in 1975. Acidity is a potential problem only where sustained fumarolic emissions are in evidence or following volcanic eruptions.

In addition to sulfur gases, evidence for atmospheric introductions of mercury and arsenic has been sought. As (III) arsine has not been detected using sample volumes in excess of  $0.5 \text{ m}^3$  collected over approximately 4 hr periods.

The initially relatively less sensitive detector tube procedures for  $\text{SO}_2$  and  $\text{H}_2\text{S}$  showed no change from the predrilling stage of May '75 through subsequent periods of flow and steam production tests up to the most recent measurements of January 1980. Even with more sensitive methods, the lowered detection limits of 30 ppb were not attained at 100 m downwind from the well head.

The upsurge of air mercury levels during flashing was originally thought to have been a "burst" releasing accumulated mercury at depth. During the July 1976 testing, it was not known that in addition to the Sulfur Bank activity a new East Rift Zone emission center -- the Heiheiahulu spatter cone about 13 km to the west of the well -- had been active for two months. Subsequently this cone was tested and found to be an intensive mercury emitter and one of the probable sources of the relatively high level recorded at the flashing of HGP-A. Subsequent

measurements, made in July-September 1977, show the presence at the well of air mercury and  $\text{H}_2\text{SO}_4$  -- although the well itself had been shut down since May 1977.

After start up, mercury rapidly approaches an asymptotic emission rate of approximately 1 g per 24 hrs corresponding to approximately 50  $\text{mt}\cdot\text{hr}^{-1}$  ( $100\text{K lbs}\cdot\text{hr}^{-1}$ ) mass flow after operating for 10 hours.

Typically, Puna District residences make use of roof top water catchments. The most serious complaints originated from the Nanawale Estates and to a lesser extent from the Leilani Estates residents South of the Kubera house. The results of analysis are all within safe water quality standards for human use.

As mentioned above, EPA guidelines for habitable dwellings are 0.5 p Ci Rn/l air and are higher by nearly two orders of magnitude than the levels observed at the well site (0.0067 p Ci Rn/l) and by nearly four orders at a distance of 0.15 km (0.00005 p Ci Rn/l). However, the "worst case" calculations indicate that as much as 1.16 p Ci Rn/l radon is possible at HGP-A which is more than double the EPA recommended safe level.

In the Puna District, Island of Hawaii, near the HGP-A well, the mean soil Hg level is about 12-fold higher than the worldwide abundance figure. This is not reflected in commensurately higher concentrations of Tl, Cu and Fe, and the local atomic abundance ratios of 8, 48.5 and 270 show this. The Hg-enrichment of the local soil is 12.3-fold relative to Fe, and in satisfactory agreement, 13.1-fold relative Cu. Both of these elements are geochemical non-volatiles, whereas Tl like Hg is volatile, albeit less so. Thus the Tl-Hg enrichment factor of only

2,4-fold. These data can best be explained by postulating an active, highly mobile source of Hg outside the HGP-A area, namely Kilauea and its East Rift. The Tl samples are too limited for any firm interpretation, but fumarolic and volcanic sources may contribute this element as they do Hg, but to a lesser degree.

Mercury injected into the atmosphere from vents, fissures and fumaroles of the Kilauea system normally contains a small percentage of particulates, the major forms of the element being  $\text{Hg}^0$  and  $\text{HgCl}_2$ . Ionic mercury entering the soil solution can be readily absorbed by plants via the roots, translocated to leaves, reduced and re-released as  $\text{Hg}^0$ . It is readily conceivable that plant-mercury relationships are not unique, and that similar source-sink-source linkages may exist for arsenic, selenium and thallium.

### THE GEOTHERMAL RESOURCE POTENTIAL

#### OF HAWAII

On the younger volcanic systems, the rock types above sea level are generally very permeable allowing rapid percolation of rainfall down to the freshwater lens which floats above the denser salt water in the basal aquifers. The hydrologic head of the basal water table increases by 0.5 meters per kilometer inland.

Impermeable ash is commonly found interbedded with the more open fractured basalt lava. This has the effect of impeding the downward flow of meteoric recharge and thus producing a localized perched water table. The near vertical dip angles of dike systems within rift zones generally hinder the seaward flow of ground water through the basal aquifer. This results in an elevated water table up slope of the dike zone and depressed water levels down slope.



On those parts of the younger islands where recharge is low, the groundwater chemistry is quite different. Both tidal mixing and upward migration of sea water salts into the basal aquifers elevate the dissolved salts concentrations considerable; longer residence times of the groundwaters also increase silica concentrations. The present geothermal assessment is based on:

Surface geology.

Infrared studies.

Seismic studies.

Magnetic field studies.

Groundwater temperature data.

Groundwater geochemistry data.

Geological: Structural geology of the islands and volcanoes, age of the islands, and age and location of most recent volcanism on each island.

Geophysical: Aeromagnetic data, gravity data, seismicity, infrared surveys, and groundwater temperature data.

Geochemical: Elevated groundwater silica concentrations and anomalies in the Cl/Mg ion ratios in near surface waters.

The survey has identified several areas in the State (see Table) which may have significant geothermal potential and which should receive more intensive site specific surveys in the future. The probability of near future development is based on the present state of the art in drilling and geothermal utilization technology, proximity to potential markets for heat/electric power produced, and local land use constraints (national park lands, urban residential zoning, etc.)

A summary of principal areas of geothermal resource potential  
in Hawaii

Location*	High Temp. Resource	Low Temp. Resource	Probability for Development
Hawaii			
1. Puna	1	1	3
2. Ka'u	2	1	7
3. South Point	3	2	3
4. Hualalai-North Kona	5	3	1
5. Kawaihae	5	3	1
6. Keaau	6	4	1
7. Kohala	7	5	8
Maui			
1. Haleakala-Southwest Rift	3	2	5
2. Haleakala-East Rift	3	2	6
3. Pauwela	4	3	3
4. Lahaina	3	1	1
5. Olowalu-ukumehame	3	1	2
6. Honokawai	5	4	2
Oahu			
1. Waimanalo	7	5	1
2. Lualualei	8	6	1
3. Honolulu Volcanic Series	8	7	2
4. Haleiwa	9	7	3
5. Laie	9	7	3
6. Pearl Harbor	10	9	1
Kauai			
1. Post erosional Volcanic Series	10	8	5

1 = highest potential

### ENVIRONMENTAL SCALE-UP

Under current projections HGP-A will be a producing 3 megawatt (electric) generating station in 1981, operating at a mass flow of 50  $\text{mt}\cdot\text{hr}^{-1}$  with a steam quality of ca 0.6.

As of January 1980, the well fluid contained about 0.001 ppm of Hg (very high estimate) and 700 ppm  $\text{H}_2\text{S}$ .

If it is assumed that the Kapoho reservoir is chemically homogeneous, and the HGP-A is a representative sample of that hydrogeothermal field, then the scale-factor for any future generating capacity, megawattage projected/3 megawatts current can be used for projecting mercury and hydrogen sulfide emissions.

The most immediate future goal for geothermal development at Kapoho is 25 megawatts. This intermediate step would be followed, if performance and economic resources warrant, by development into 200-500 megawatt range. The latter is a projected ceiling for the Kapoho reservoir based on continuous operation into the late 21st century.

Beyond this single highly promising reservoir are the additional hydrogeothermal fields on the Island of Hawaii, with perhaps a potential of 1000 megawatts and a total ceiling value for the state lying between 2000 and 3000 megawatts.

Following present chemical emission stands, two potential limits to the overall development of geothermal energy resources are mercury and hydrogen sulfide. These limits are embodied in the EPA's National Emission Standards 121:0461 (1976) and the more recent 40 CFR 51.24, Fed. Reg. 43 (118):26382 (1978), the 1977 Clean Air Act: Prevention of Significant Air Quality Deterioration (PSD).

The former sets upper limits on Hg output of 1600 or 2300 g per 24 hr. period, depending upon the nature of the facility. Using HGP-A as the operating model and assuming the Kapoho reservoir to be broadly representative of reservoirs, no amount of scale-up seems capable of attaining emissions limits for Hg, even on a statewide level.

And it is reasonable geochemically to expect the highest Hg levels to be associated with the Island of Hawaii.

The PSD limit for geothermal  $H_2S$  from specific source is 250 tons per year. For present purpose, we define the Kapoho field as a source; hence, the 250 ton limit would apply not only to HGP-A as a generating facility, but to all subsequent wells and power stations on the Kapoho reservoir. Obviously, HGP-A itself, unabated, is itself marginal assuming continuous operation at a mass flow of  $50 \text{ mt} \cdot \text{hr}^{-1}$  and that the 700 ppm  $H_2S$  content is a steady state value under operating conditions.

Results of the well test completed in January 1980 show that of the 700 ppm wellhead  $H_2S$ , 22 ppm are released after caustic soda treatment and the use of the rockpile sparger system (L. Lopez, HGP-A Project Manager personal communication, February 1980). This gives an abatement value of 97%. At this efficiency any power rating up to 90 megawatts would fall within PSD limits. If  $H_2S$  abatement were to reach an efficiency of 99% then the limit at Kapoho would become 268 megawatts. A 1000 megawatts output would be permissible if 4 or more of the 7 identified reservoirs were able to divide the emission burden more or less equally.



## WORKSHOPS

The first workshop was held on 2 March 1979. Over fifty people attended. The names of the individuals and their affiliations are attached on a subsequent list. The broad environmental concerns of hydrogen sulfide and heavy metal pollutions were expressed, but many felt that the state of the art in technology could probably keep these within environmentally acceptable limits, if industry felt sufficient pressure from the populace to so do. The noise issues were of major concern, especially since Hawaiian houses are designed in such a way that there is little or no noise attenuation indoors when compared to outside. Dr. Burgess, who presented the major issues on noise concern, will be preparing a section of Overview detailing the local and unique noise considerations in Hawaii.

The luncheon speaker, Dr. Gene Grabbe, Manager, State of Hawaii Center for Science Policy and Technology Assessment, Department of Planning and Economic Development, stated firmly the Governor's commitment to island self-sufficiency. He also stated that alternate energy development will have high priority within the various allocations from the State Capitol.

The first workshop was held in Honolulu at the East-West Center.

The second workshop was held May 3 and 4, 1979 at the University of Hawaii at Hilo and over 75 people were in attendance for at least part of the two day session. The range of interested individuals was surprising, ranging from high school students who came faithfully each day after school to "interested citizens" and technically trained people. Copies of some of the papers presented have been included in the section on "The Socio-Economic Issues of Geothermal Development";

Other papers were presented by individuals who will be preparing lengthy papers to be included as volumes in these Geothermal Overviews. However several persons presented papers of significance to geothermal development which will be attached to this summary. Dr. Louis Goodman will be publishing his paper separately. The press covered both workshops and several television stations did "spot news" announcements of the Honolulu meeting.

The Honolulu Advertiser, on March 3, 1979, stated that "The effects of noise and air pollution were some of the environmental issues that cast a cloud yesterday over discussion of the future of geothermal energy projects in Hawaii." But they went on to say that "early resolution of these problems will pave the way for an environmentally acceptable development. The report is expected to play a role in the future allocation of federal funds for environmental issues."



# University of Hawaii at Manoa

Pacific Biomedical Research Center

Snyder Hall · Room 210 · 2538 The Mall · Honolulu, Hawaii 96822 / Cable Address: UNIHAW

February 14, 1979

You are invited to participate in a Geothermal Overview Project on:

2 March 1979

8:45 a.m. - 5:15 p.m.

East West Center - Asia Room

University of Hawaii at Manoa

These workshops are to provide the Assistant Secretary for the Environment, Department of Energy, Washington, D. C. with a preliminary impact assessment for geothermal development in the State of Hawaii. Their primary purpose is to identify issues - in the broadest sense from geological implications to psychological and sociological concerns - and it is expected that both the State and the Federal Governments will seriously address themselves to the questions and issues raised. It is the intent of these "Overview Workshops" to educate and to offer a forum to all individuals, businesses, organizations, etc. who are interested in geothermal resources development.

You are also invited to be our guest at lunch.

If you have any questions or would like further information, please contact me.

Sincerely,

*B. Z. Siegel*

B. Z. Siegel  
Project Manager,  
Geothermal Overview for  
the State of Hawaii.

Phone: 948-8187 or 948-8043

\* "Overview" Projects are sponsored by the Department of Energy (D.O.E.) contract to the Lawrence Livermore Laboratories of the University of California.

## GEOTHERMAL "OVERVIEW" FOR THE STATE OF HAWAII - HONOLULU MEETING

## TENTATIVE AGENDA

for

2 March 1979

Asia Room East-West Center, University of Hawaii at Manoa

- 8:45-9:15 Registration
- \* 9:15-9:45 Introduction: Dr. John Shupe, Dean, University of Hawaii, College of Engineering; Director, Hawaii Geothermal Project; 1977-78 Scientific Advisor to the Ass't Secretary for Energy Technology, U.S. Department of Energy
- \* 9:45-10:15 The impact of "Overview" Projects in California: Dr. Philip Leitner, St. Mary's College, California
- 10:15-10:30 Coffee Break
- \* 10:30-11:00 Possible geothermal Areas in Hawaii-short and long term predictions. Dr. Don Thomas, Asst. to director, Hawaii Institute of Geophysics
- \* 11:00-11:30 Hawaiian Electric Company's Prospectives on Geothermal Development
- \* 11:30-12:00 Broad Environmental Concerns: Dr. Clifford Smith, Director of the National Park Service's Cooperative Program for Hawaii, and Associate Professor of Botany
- \* 12:00-1:30 Lunch at the East-West Center  
Speaker: Dr. Gene Grabbe, Manager, State of Hawaii's Center for Science Policy and Technology Assessment
- \* 1:30-2:00 Human health concerns: Frank Tabrah, M.D., Professor of Family Practice and Community Health, John Burns School of Medicine
- \* 2:00-2:30 Noise: Dr. John Burgess, Acoustical Engineer and Professor of Mechanical Engineering
- 2:30-2:45 Cofffe Break
- \* 2:45-3:15 Air Quality: James Morrow, American Lung Association
- \* 3:15-3:45 Sociological issues: Dr. Penelope Austin, Visiting Professor in Sociology
- \* 3:45-4:15 Legal constraints and Hawaiian land laws: Dr. Robert Kamins, Dept. of Land and Natural Resources, State of Hawaii
- \* 4:15-4:45 The need for predictive modelling, and closing statements: Dr. W. Molenkamp, Lawrence Livermore Laboratories, University of California
- 4:45 Happy Hour at the Ohana Room

\* Each speaker is requested to allow at least 10 minutes for questions and discussion from the participants.



## GEOTHERMAL OVERVIEW WORKSHOP

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John Burgess	UH	Holmes 200	948-7544
Clifford Smith	UH-Dept. Of Botany	3190 Maile Rd.	948-8218
Alvin Char	Tripler Army Med. Center		433-6661

# GEOTHERMAL OVERVIEW FOR THE STATE OF HAWAII

## WORKSHOP

Sponsored by the Department of Energy Grant to the Hawaii

Natural Energy Institute \*

## AGENDA

### THE ISLAND OF HAWAII

May 3 and 4

University of Hawaii at Hilo  
Campus Center #307

#### May 3

8:00-9:00 am Registration

9 am Opening remarks by Bennie DiBona, Director,  
Division of Geothermal Energy, Department of  
Energy, Washington, D. C.

9:20 am Geothermal development in the Western United  
States and Hawaii's position. Tony Adduci,  
San Francisco Office of the Department of Energy.

9:40 am The Overview Program. Paul Phelps, Lawrence  
Livermore Laboratories of the University of  
California.

10:00 am A broad look at environmental issues. Lynn  
Ansbaugh, Lawrence Livermore Laboratories of  
the University of California.

Approximately 30 minutes for questions, discussion and coffee.

10:45 am Broad issues of Hawaii's geothermal development.  
Jack Keppeler, Managing Director, County of Hawaii

11:15 Hawaii: A case study of geothermal development.  
Louis Goodman, Resource Systems Institute of  
the East-West Center, Honolulu.

\* B. Z. Siegel, Project Manager, University of Hawaii at Manoa  
Honolulu phones: 948-8187, 948-8043, 948-7488.

May 3

- 11:45 Political, environmental and human concerns of geothermal development. Jeremy Harris, ConCon delegate from the Island of Kauai and Marine Affairs Coordinator for Kauai.
- 12:15-1:15 Lunch at the Campus Center
- 1:15 pm Solutions available to Hawaii to solve her energy needs. Paul Yuen, Director, Hawaii Natural Energy Institute.
- 1:45 pm County of Hawaii's Energy Self-Sufficiency Program. Y. Hahn, director.
- 2:15 pm Geothermal and the electric company. Daniel Williams, Hawaiian Electric Company, Hilo.
- Approximately 30 minutes for discussion, questions and coffee.
- 3:15 pm The impact of geothermal development on the local geology. T. Casadevall and Dallas Jackson, Hawaii Volcanos Observator, U.S.G.S.
- 3:45 pm The impact of geothermal development on the National Parks of Hawaii. D. Ames, Superintendent, Hawaii Volcanos National Park.
- 4:15 pm The impact of geothermal development on the ocean's beaches--flora and fauna, etc. Keith Chave, Professor of Oceanography, UHM.
- Approximately 30 minutes for discussion and questions.
- 7:30 pm Informal session -- all are invited. Location to be announced.

May 4

- 9:00 am The state of the art in geothermal development - engineering considerations. W. Chen, Site Engineer, Hawaii Geothermal Project, Puna.
- 9:30 am The state of the art in geothermal development - the gases and effluents. D. Thomas, Hawaii Institute of Geophysics, UHM.



May 4 continued

10:00 am Noise. John Burgess, Acoustical engineer. UHM.

10:30 am Discussion, questions and coffee

10:45 am Social and Cultural Impact of Geothermal development. J. Johnson, Psychologist. UHH.

11:00 am Community Concerns: a presentation coordinated by the Puna Hui Ohana from Pahoa.

12:15-1:15 Lunch at the Campus Center

1:15 pm Community concerns, continued.

2:15 pm Health considerations. George Bracher, M.D. Hilo, Hawaii.

2:45 pm Hawaii's endangered species and geothermal development. C. Lamoureaux, UHM.

3:15 pm Discussion, questions and coffee

3:30 pm Summaries of the geological issues. Joseph Halbig, geologist, UHH.

4:00 pm Summaries of the biological/environmental issues. S. Siegel, environmental biologist, UHM.

4:30 pm Summaries of the socio-economic issues. P. Austin, sociologist, UHM.

GEOHERMAL OVERVIEW WORKSHOP - HILO MEETING  
May 3 and 4, 1979

Lynn Ansbaugh  
Paul Phelps  
Keith Chave  
Frank Howarth  
Barbara Yount  
Carol Feldman  
Barbara Chapman  
Micki Altizer  
Bill Chen  
  
Dave Ames  
Don Reeser  
Philip Leitner  
Jerry Johnson  
Tony Adduci  
Nelson L. Ayers  
Lani Matsumoto  
Susan Shishido  
Tetsuo Miyabara  
James Moreau  
Mae Mull  
Norman Oss  
Tom Casadevall  
P. Quentin Tomich  
Arnold Okamura  
Jeremy Harris  
Bennie G. DiBona  
John P. Keppeler  
H. D. Williamson  
Carl Vesey, P.E.  
Don Thomas  
Paul Yuen  
Richard L. O'Connell  
Amy Hamane  
Tim Rodrigera  
Dallas Jackson  
Jitsuo Niwao  
Young Ki Hahn  
Peter K. Hauanio  
Wil Turner  
John C. Burgess  
Penelope Austin  
Tomas Daniel P. Jimenea  
Charles H. Lamoureux  
Mahealani Naungayan  
Sara Hauanio  
Everett Kinney  
Robert Ratliff  
Simeon Enriquez Jr.  
Bill ?  
Jill Nishimura  
Judy Nakata  
Sherri Ann Tomono  
Cathy Nakamura  
Takani Bohannan

Lawrence Livermore Laboratory  
Lawrence Livermore Laboratory  
University of Hawaii-Manoa, Oceanography  
Bishop Museum  
East-West Ctr., Resource Systems Institute  
University of Hawaii-Manoa, Geothermal Overview, G.A.  
University of Hawaii-Manoa, Geothermal Overview, G.A.  
  
Research Corp. of the University of Hawaii/Dept. of  
Planning and Economic Development  
Hawaii National Park  
Hawaii National Park  
St. Mary's College, Moraga, CA  
University of Hawaii-Hilo  
U.S. Dept. of Energy, San Francisco Office  
Puna and Kau Soil and Water Conservation District  
University of Hawaii-Hilo  
University of Hawaii-Hilo  
East-West Ctr., Resource Systems Institute  
Hawaiian Dredging and Construction Co.  
P. O. Box 275, Volcano, Hawaii\_Hawaii Audubon Society  
Hawaii Electric Light Co.  
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Hawaii Chapter, Wildlife Society  
USGS  
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Dept. of Energy-Washington D. C.  
County of Hawaii  
Hawaii Electric Light Co.  
Carl Vesey Associates, Hon., HI  
Hawaii Institute of Geophysics, UH Manoa  
Hawaii Natural Energy Institute, University of Hawaii-  
Office of Environmental Quality Control  
American Lung Assn.-Hawaii Chapter  
University of Hawaii-Hilo  
USGS-Hawaii Volcano Observatory  
Hawaii Electric Light Co.  
County of Hawaii/University of Hawaii-Hilo  
Puna Hui Ohana  
Youth with a Mission, Kailua-Kona, P.O. Box 2399  
University of Hawaii-Manoa, Acoustical Engineer  
University of Hawaii-Manoa, Sociology  
University of Hawaii-Manoa, East-West Ctr.  
University of Hawaii-Manoa, Botany(endangered species)  
Puna Hui Ohana  
Puna Hui Ohana  
Puna Hui Ohana  
University of Hawaii-Hilo  
Puna Young Adult Hawaiian Club  
Hawaii Electric Light Co.  
Waiakea High School  
Waiakea High School  
Waiakea High School  
Waiakea High School  
Waiakea High School

Norma Barroga  
 Craig Severone  
 Norb Keolanui  
 Bill Reich  
 Earl Harbin  
 Carrie Takaki  
 Tammy Nishino  
 Maureen Sato  
 Norma Manson

Kini L. Pe'a

Robert M. Pyle

Joseph Halbig  
 Sanford Siegel  
 Louis Goodman

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 Puna Hui Ohana  
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 The Nature Conservancy  
 1234 N.W. 25th St., Portland, OR 97210  
 University of Hawaii-Hilo, geologist  
 University of Hawaii-Manoa, Botany  
 East-West Ctr., Resource Systems Institute, UH Manoa

## Broad Issues of Hawaii's Geothermal Development

By

Jack Keppeler, Managing Director, County of Hawaii

Geothermal energy is an alleged but still unproven replacement for fossil fuels in Hawaii. It is also alleged that this change can be to the social and economic benefit of the citizens of Hawaii. The next several decades will test the people and all their social institutions: economic, social, and political formats.

It all comes down to a choice of life-styles. A change in the energy supply will dramatically effect our choices. Some are iterated.

1) Growth or no growth? Growth means increasing the employment base, wealth but also increasing population and a change in lifestyles. No growth means retrogression and reduction of population.

2) Distribution of wealth. The basic underlying issue of Geothermal energy is the issue of wealth distribution. Does the resource belong to the private citizens of Hawaii or to the Native Hawaiians? I believe this will be solved by 30 years of litigation.

3) Physical environment. If there is additional geothermal development, does it mean greater industrial growth in this profoundly agrarian economy?

4) Free market or controlled economy. You don't have a controlled economy and a free lifestyle. You don't have a free marketplace devoid determination.

This is an important era full of changes. Energy is the arena for the above debates to continue. Eventually we must decide if we have outlived participatory democracy.

Q: Where do you see the Big Island on the issue of government regulation of free market play on geothermal over the next 10 years?

A: At the present and near future government's role is as a goader. We have the mechanisms now to put together a municipal power authority and we can go before the public utilities commission as an advocate. These two faces appear to be adequate.

Q: With so many alternate sources of energy here, which is to receive priority and in what order will they be developed?



A: With an abundance of energy, irrigation of traditionally arid areas of the Big Island might become possible. The problem is to see the possibilities.

Q: Why with the abundance of non-fossil fuel sources should nuclear energy be a must in the 20th century as you say?

A: Nuclear energy is a boogeyman. In case of a no-growth policy, the Big Island may not be worthy of nuclear power in the 20th century.

Political, Environmental and Human Concerns  
of Geothermal Development

By

Jeremy Harris, Marine Affairs Coordinator for Kauai

Geothermal energy potential must be evaluated in the broad sense of societal need before it is developed.

1) What is our long range goal? What type of human ecosystem do we want to create? We need to define very carefully societal quality and style that we hope to achieve in the long run.

2) Does geothermal energy further us towards this goal? If not, it should not be developed.

3) What will be the immediate environmental impacts (noise, pollution, etc.) and attempt to mitigate them?

This is the three step process which should be used in evaluating a new technology.

The goal of my constituents in Kauai is to develop a rural, highly self-sufficient community that maintains a quality environment and a stable economy, whose populations and economy is in Dynamic equilibrium. There are limits to growth--limits of land and resources. The goal is dynamic equilibrium at a pre-determined carrying capacity/lifestyle.

Correctly developed, geothermal energy could contribute to this desired future as one of several local energy sources. But incorrectly developed it could promote rapid population growth or large polluting industries. We need well defined goals, responsible public officials and vigilant electorate.

Q: About benefits to society--you seem to refer to Kauai or the State of Hawaii as your societal unit?

A: Kauai or the State is a political unit, an environmental unit, an energy-producing unit. So I see no problem in the people of Kauai deciding what kind of societal style they want.

Q: How can we hold no population growth as a goal when we have immigrants who are attracted to Hawaii and both they and the young people here need jobs?

A: I think population is the single most important issue the state faces. We have a finite system. Carrying capacity is a qualitative judgement that must be made by the community about the

lifestyle they want. Then it is the governments' job to work out means to control the population.

Q: Where is it written that the people of Kauai have established societal goals?

A: The State plan is a first shot. The State goal of limited growth is another. I am speaking as a politician who is reading his constituency. Recent events on Kauai indicate the people do not want an urban ecosystem. The councilman who espoused slow growth and agricultural self-sufficiency got the largest number of votes.

## HAWAII'S ENDANGERED SPECIES AND GEOTHERMAL DEVELOPMENT

Charles Lamoureux  
University of Hawaii, Manoa

Interests of geothermal development may very well not be congruent with concerns for endangered species protection. The maze of state and federal laws and environmental regulations that concern themselves with endangered species protection must be addressed.

An endangered species is, by law, one which is in immediate danger of extinction. A threatened species is one which is in immediate danger of becoming endangered. Thus there are two legal levels of endangerment, but endangered species legislation protects both categories to approximately the same degree. There are species which biologists, by biological definition, would conclude are threatened with extinction. There are also those which are legally covered, which have met all the tests of law, which must be dealt with in any environmental assessment of a project such as this one. There is also an intermediate category, which gets somewhat sticky, and most Hawaiian species are in the middle ground somewhere. The U.S. Forest Service recognizes a category of "sensitive" species, that is, those species that have been proposed and listed in the Congressional Record as being considered for naming as endangered species, but which have not yet passed all the way through the rather complex process.

For example, in Hawaii, depending on which list you follow, there are on the order of 600 proposed endangered plants, but only one species which has made it all the way through the mill. There are about 600, then, which are in this realm of sensitive species. The Forest Service in most of its activities considers these species in much the same light as the legally endangered species, but not all government agencies do so.

The basis for endangered species legislation was Public Law 93-205 of 1973, the Endangered Species Act. It was so extensively modified in 1978 that most people are not yet sure what all the effects of the 1978 modifications will be. Basically the Endangered Species Act prohibits the import, the export, and the use in interstate and foreign commerce, of endangered species. It also prohibits the taking of animals (but not plants) that are considered endangered. The State law goes beyond this by also prohibiting the taking of endangered plants, and the State law includes all those species that are on the federal list plus such others as the State may designate. At least as far as plants are concerned, there are no species yet on the State list which are not also on the federal list.

The major effect of the federal endangered species law on projects such as this one is in Section 7 of that federal law, which says, in effect, "the Secretary of the Interior shall review other programs administered by



him and utilize such programs in furtherance of the purposes of this act in the protection of endangered species. All other federal departments and agencies shall, in consultation with the assistants to the Secretary, utilize their authorities in furtherance of the purposes of this act, by carrying out programs for the conservation of endangered and threatened species, listed pursuant to Section 4 of the Act, and by taking such action necessary to ensure that the actions authorized, funded, or carried out by them do not jeopardize the continued existence of such endangered species and threatened species, or result in the destruction or modification of habitat of such species, which is determined by the Secretary after consultation as appropriately affected to be critical."

In other words, the law would prohibit the use of federal funds for a project which was found to be detrimental to endangered species. And since much of this particular project, as well as most other large scale projects in Hawaii, is funded federally, this becomes a matter of some importance.

Largely, I think, because of the snail darter - Tellico Dam case, with which you are all familiar, extensive modifications were made to the Endangered Species Act last year, including some modifications in Section 7. The major one of these is that a consultation procedure was set up with the states and a so-called "God Committee" was created (because it presumably has the right to determine whether a species will survive or not). That review committee consists of the Secretary of the Interior, the Secretary of Agriculture, Secretary of the Army, the chairman of the Council of Economic Advisors, the administrator of the Environmental Protection Agency, the administrator of the National Oceanic and Atmospheric Administration, and a state representative as appointed by the President after consideration of recommendations from the Governor or Governors of the affected state or states. That committee has considered at least two actions where the presence of an endangered species threatened or promised to prohibit the development of a federal project. One of these was the Tellico Dam. It is interesting to note that this review committee, after careful review, considered that the dam should NOT be allowed to continue. There was a second case, the Grayrocks case in Wyoming, where an exemption, or a partial exemption was granted, and the project was allowed to proceed. So there are some ways around the intent of the Endangered Species Act, but it's not going to be easy getting around it.

That's basically the legislation with which one must deal, and we should turn now to consideration of the situation with endangered species in Hawaii, where for historical and evolutionary reasons which I won't go into here, we have more endangered species than any other state in the country; in fact, as many as all the others put together, at least in terms of those that have been proposed for listing.

Hawaii has 639 proposed endangered plants, and 194 proposed threatened.

There are no other states that come close, except perhaps California. In Hawaii, 639 or 29% of the total flora are proposed for listing as endangered species. In the rest of the country, including Alaska, 761 or 3.8% are proposed. Also, the land area of Hawaii is about .2% of the land area of the rest of the U.S. There are many more threatened species in the rest of the U.S. than in Hawaii, but this may just be an indication that many of ours are even rarer and closer to becoming extinct. In addition to these numbers which were put together about three years ago, something like 250 Hawaiian species have become extinct. Our information on these goes back only 200 years, to Cook's voyage. For the rest of the U.S. the information goes back in some cases as far as the 16th Century, so we have roughly 400 years of information. But  $2\frac{1}{2}$  times as many plants have become extinct in Hawaii in 200 years as in the rest of the U.S. In 400 years you could come up with similar numbers for birds, land snails, tree snails...and these numbers are really just a reflection of the very fragile nature of the island species, or organisms that evolved in places where the main predators were not tigers or lions, but little caterpillars, and where the main grazers were not cattle or sheep or goats but, again, little insects, and maybe flightless geese. Bringing in cattle, bringing in dogs and pigs, has resulted in a great upset in the natural ecosystem, and rapid loss of species has been the consequence. Whatever the reasons are, these are facts which, although they may at times be politically embarrassing, and may be very difficult to live with, are still biological facts that have to be considered.

There is at the moment one endangered plant which has passed through the process and been listed for Hawaii. It is the Hawaiian broad bean (*Vicia menziesii*), which happens to be found on this island (Hawaii), in the Kilauea Forest Reserve and on the Keahou Ranch at about 5200-5400 feet altitude. (This plant will also be the subject of a stamp being issued this month, part of a series of 4 stamps on endangered plants of the U.S.)

One of the plants which has been proposed for listing, but which is not there yet, is an inconspicuous little fern which 100 years ago apparently was found on all the main islands, but within the last 30 or 40 years has been found only on this island, and in recent years, only in one place in Puna, along the rift zone of Kilauea, just outside the National Park boundary. It is not in the area of current geothermal development, but it is in Puna, and it is on the rift zone, and it is the kind of thing that may have to be considered in the future.

There are special concerns as far as geothermal development goes, and the exploration and drilling phase is one of these. This may involve some land clearing. The development of power plants will also involve land clearing. That will, then, involve the removal of plant species from an area, and the disruption of bird species. It becomes important to have some kind of environmental assessment beforehand to determine what is in the area. Such a survey was done for the plants in the Puna site. It happened that in that area there were no plants that



were even proposed for consideration as endangered species. But the site is particularly important. There was recently a proposal for what I believe was a negative declaration to allow for drilling in the PuuWaawaa area on this island. This IS a region where there are a number of rare plants that have been proposed for inclusion on the endangered species list. Much would depend here, as far as a potential negative impact, on exactly where the drilling was done. It becomes very precise--in some cases there may be an acre containing a number of endangered species, while a short distance away there are none at all. Some of the endangered species have very small, very narrow distributions, which must be rather precisely known to assess potential impacts.

There are in Puna, as our Hawaiian friends mentioned this morning, the hawk, the io; in upper Puna at least the ou and the akiapolaau. These may not be at the site of the current project, but perhaps in areas where future development may occur. It is important to make a census of what is in an area so that we know what is there that may be affected.

Dr. Burgess was asked how noise affects birds. I can't really add anything significant to his comments, but I should mention a couple of additional considerations. If we're going to find out how noise affects birds we're going to have to do some long term studies, because noise may affect birds differently during the breeding season, or when there are young hatchlings around, or at other times. Also, in order to know what birds are in an area, we can't just have an ornithologist walk through one afternoon and say there's nothing here. You must consider noise, then, not just at one time, but noise at different times that may well have different effects. One other thing that occurred to me as I listened to John Burgess was that the Hawaiian bat might also be in the area. If the bat or any other organism that uses echo location to find its food is in the area, are these interfered with at all? Birds in other areas may not be affected by noise (e.g., the albatrosses living happily by the runway at Midway), but we cannot say how local birds will react, such as the ou, a very rare honeycreeper found in the area.

As far as the fumes and the effluent pool are concerned, we have heard about the means that will be used to cleanse these in this particular project, and considerable care has been taken to ensure that these are environmentally compatible at the time of their release. We do know that volcanic fumes have effects on plants, and presumably some of the geothermal fumes might. For instance about 40 years ago in Hawaii Volcanoes National Park near Puhimau crater, which is known as the Puhimau hot spot, there was an area which began fuming where there was a complete change in vegetation. The forest disappeared and was replaced by grassland. It just so happens that in that area now there is also a very rare plant that's restricted to that hot spot. So there may be different effects, and some of these may promote certain endangered species. The point is that you have to consider these things. You can't just say there will be no significant environmental effects.

This plume contains a lot of steam, and this could result in changes in the moisture regime, and, again, changes in vegetation which could affect endangered plants. For example if the PuuWaawaa site were ever to come into production and steam were released in that area to any great extent, this could conceivably change the moisture regime, and this might affect some of the endangered plants in that area.

We really know very little about the effects of air pollution on endangered species in Hawaii, and it's also very hard to study them, especially once a species has become protected, because even scientists have a great deal of difficulty getting the permits they need to collect the species in order to do the studies that need to be done.

The wastewater as we have heard will be released into a pond. There may ultimately be larger quantities that will be reinjected. If some of that wastewater were eventually to flow off into streams, there may be some effects on stream life, but it seems as if in this particular project this has been taken into consideration. If by any chance some of the wastewaters from this project were to reach lava tubes, which have their own very fragile ecosystems, this could cause some other kinds of problems.

I have tried to discuss some of the problems and concerns about endangered species, and some of the difficulties in obtaining the information that is needed just to address these issues. In closing, let me just say that the problems at each site will be different. Problems in Puna would be different from those encountered in a low, dryland site. The organisms would be different, and the possible consequences would be different. Therefore an environmental assessment, a very careful one, needs to be made at any geothermal site, even before exploratory drilling phase, to at least indicate the potential problems, and that initial assessment should not be a one shot deal. It should be made over a reasonable time period and it should be a continuing assessment.



### QUESTIONS AND COMMENTS

Q. If you very tightly specify an area where there is an endangered species, then everybody and his cousin goes through to look for it and take one home. On the other hand, if you don't say specifically where it is, then they can't find it, it's quiet, but they may bulldoze and destroy it anyway. Is there a compromise?

A. This is a real problem, and the law is beginning to speak to it. It has been that a species could be put on the endangered species list without its critical habitat being defined. I believe as a result of the 1978 modifications, you are going to have to define the critical habitat at the same time as the species is being proposed for inclusion on the list.

Q. Perhaps you were going to say this, but I believe there are exceptions for species for which this could prove fatal, or for which this is impossible to do.

A. This is true, but it can be done, according to the new modifications, it will be done, and that will take care of it in part. For some of the very rare things, that critical habitat might not be bigger than this room. Once the boundaries are defined, they are published in the Federal Register and they become common knowledge. This still doesn't mean that the boundaries will be enforced and the area protected. But at least with most species, the critical habitat will be designated at the same time the species is listed. In the meantime, it is a problem. We are trying now to find out as much information on endangered species as we can, assembling all the information from past studies, with people going out and trying to pinpoint these areas on the map very precisely. The problem is that you then put the map on display; it becomes part of the official record, subject to public access. The seed collector can get in there and rip the plant off before it is protected. So one treads very carefully to collect the needed information for legal purposes without tipping off the unscrupulous exploiter of the species.

Q. What I've seen at the conference so far is a decoupling of geothermal development from the other developments that tend to follow. Geothermal is particularly vulnerable to that--just one small wellsite is one thing, one problem, but sure to follow is the whole urbanization process. We shouldn't restrict our biological studies to just the one site, but for the whole thing. What is the possibility of federal funding for a larger scale biological study, such as is being done for the sociological study?

A. I haven't raised this point because it was brought up by the people from Puna this morning, but it is an issue in any major project, such as on Oahu, whether there should be a second harbor at Barber's Point. It's one thing to do an environmental impact statement for the land you're going to dredge to make the harbor and build the docks. There's been con-

siderable argument whether you ought to couple that with what's going to happen when you build a city with 100,000 people, on the edge of it. Should you hold up the permit for the harbor until you've done the study for the whole thing? This becomes important now in Puna, obviously. It is more than just a matter of endangered species legislation...it's a whole environmental assessment, tied in with the whole assessment of economic costs and benefits. I thought it was a little outside of the scale of my talk, but I'm glad you raised the issue.

Q. When we got the invitation to this conference we received a map showing many potential geothermal sites on this island and on the other islands. Apparently some of these are closer to investigation than others. From this map I gathered that certain of the Big Island sites will be further investigated, and I wondered just what the status is of say, South Kohala, North Kona, and the one down in Ka'u.

A. (from Don Thomas) The status as far as the Big Island is concerned is we are planning to do intensive studies in Kawaihae and Kona. Ka'u is probably several years away. We are going to do some investigations in Keaau. What we're simply going to do is investigate and see if the resource is there, and then make the information public and let the process take its course. All our project is intended to do is attempt to identify the resource. If we find one, it is then up to the environmental people to decide whether there are any endangered species there.

Q. Does that involve any drilling?

A. No, it will be surface measurements, soil sampling...

## SOLUTIONS AVAILABLE TO HAWAII TO SOLVE HER ENERGY NEEDS

Paul Yuen  
 Director, Hawaii Natural Energy Institute

I would like to talk to you about what the State's program is in natural energy resources, and how it might relate to the main topic of today's discussion: Geothermal.

I'm sure you've heard the fact that Hawaii is really dependent on imported petroleum. This is true. Well over 92% of our energy needs are satisfied by foreign petroleum that comes from a variety of locations. Seven percent is satisfied by wastes, primarily bagasse, and 1% by hydroelectric. What we are trying to do is reduce the size of this very large "pie slice" that is imported petroleum. If we address the energy that is used to produce electricity, there is some change, but not very much. We will use, in the production of electricity, 85% petroleum. Bagasse now takes up a larger percentage, and the others, like hydroelectric, now are about 2%.

All of this doesn't make sense, because Hawaii has an abundance of natural energy resources: geothermal, ocean, primarily ocean thermal energy, biomass--organic wastes, direct solar energy, and finally, a newcomer, but one which seems to be gaining quite a bit of momentum: wind energy.

I would like to first go over ways in which we can use natural energy resources to generate electricity. The first way is the conventional, oil-fired power plant. The oil comes from storage tanks, goes into a boiler, which boils water and produces steam. The steam expands into a turbine. The turbine shaft turns a generator, and this produces electricity. Along the way, a condenser cools the steam, brings it back to the boiler, and we start the cycle over.

Geothermal energy is somewhat different. Basically, again, we want to turn a generator to produce electricity, and we use steam to do that. In this case there is a magma chamber as the source of energy, which heats up a reservoir. The reservoir, then, when pressure is reduced, allows a combination of steam and water to flow up the well, where it is controlled by a valve assembly. A separator separates the water, which is discarded, and the steam, which is used to drive the generator. The condenser, again, is used to condense the steam back to water, and sends it to a drainage pond, or removes the water. This, then, basically is the one you're interested in. The main thing is that steam is produced to drive a turbine, not by boiling water, but by getting it directly from a natural source.

Another method which is of interest to us is bagasse. Again, we want to get heat to boil water. In this case, the sugar mills, in the processing of sugar cane, have as a waste product bagasse. Bagasse generally is blown into a burner which then produces heat and boils water, producing steam. The steam expands, and again we go through the same process.

We can use wood chips, such as from eucalyptus or giant haole koa, in which there is a great deal of interest. The wood chips are used in place



of the bagasse or oil to produce the heat to boil the water, produce the steam, which turns the turbine, which turns the generator, which produces electricity.

The OTEC plant is again basically the same thing. We have a source of heat and we have a source of cold. The source of heat boils something, the source of cold condenses it. Because the source of heat is not very hot, namely around 78 to 82 degrees, we've got to find something that will boil at that temperature. For the OTEC case it's pretty well decided that it's going to be ammonia. The cycle is as follows. The warm water, which takes the place of the heat source, is used to boil the ammonia. The ammonia, as it is boiled, turns to vapor. The vapor expands, turns a turbine, drives a generator, which produces electricity, which comes to shore, and then the vaporized ammonia is condensed in the condenser back to liquid form, and the cycle repeats.

In the wind energy conversion system--wind machines or windmills--the wind turns the rotor blades which turns a shaft, which, through a gear assembly, turns a shaft to the generator, which produces electricity.

A technique which is not present in Hawaii but which is undergoing at least conceptual tests is a solar power tower. Here you have heliostats, or basically reflectors, which reflect the sun's energy up to a central point on the tower, and gives us a tremendously high temperature source of energy which can be used to boil water or other fluids. This can be used, once again, to produce electricity.

Then, of course, you are familiar with solar cells. Light incident on a photovoltaic cell, say a silicon cell, knocks off electrons, produces an electrical current, and from this, again, we get electricity.

Let me very briefly go through some of these systems and give you some idea of what the status quo is.

Geothermal energy is energy from the earth's heat. Flashing of the geothermal well took place in '76, and we ran the well for 4 hours. The velocity of the fluid was sonic, and we've estimated that the energy out of the 6 inch pipe is roughly equivalent to a 747 at takeoff. As a result of a number of tests we found the following, which is a very quick summary of what the well's characteristics were.

It turns out that the formation is very tight, which means that the rock around the well is not very permeable, which means that the fluid flow is not as great as it could be. The well has extremely high temperatures--it is the hottest known temperature in the U.S., and it's almost as hot as the one well in Iceland. The highest temperature that we measured was about 358 degrees C. The water is quite clean, only slightly brackish. When we finally produced water, the workers were actually drinking it and said it didn't taste bad at all.

There's a potentially large reservoir there, although we don't know exactly how much. One of our investigators has estimated that the reservoir might have the capacity of about 200 megawatts for one hundred years at least.



Because of the very high temperature, there is a very high silica content. Because of the very high temperature, and because of the very tight formation, the borehole contains steam and water at saturation. This means that the flashing occurs in the formation. We're very easily able to get the 100 psi at 50 kilopounds per hour or more; as a matter of fact, we're able to get more mass flow now, which means it's easy for us to get the potential output of 3 megawatts. The flows have increased with each test as we've continued to flow that well. It turned out that the mass flow and the steam flow have continued to increase.

In addition to the electrical application of geothermal (I might mention that because of the extremely high temperatures, we have a well that's very good for electrical generation) it's possible that there are a number of applications that are non-electrical: industry, agriculture, possible use for households and health spas. Jim Moreau and his group are going to be sponsored by the Department of Energy to study the possible nonelectric uses of geothermal energy. In many parts of the U.S. they're looking at wells that have temperatures of maybe 180°C. There it's very difficult to get efficient electrical generation.

The next topic I would like to go into is OTEC, or Ocean Thermal Energy Conversion. Most of the effort is going to take place off Keahole Point, which is on the western part of the Big Island. There are three major programs. The first is the OTEC Seacoast Test Facility, which is a joint project of Hawaii County, the Marine Affairs Coordinator, the State, represented by the Department of Planning and Economic Development, and the University, represented by the Hawaii Natural Energy Institute. It's basically a program to test the components of the OTEC facility. It's presently funded by the federal government and the State of Hawaii. It is scheduled to operate for ten years, and we're in the final design phase right now. This is going to be a significant project, because with this one I think the County of Hawaii really stands to be the Woods Hole and the Scripps of the U.S. and the world of ocean energy and ocean agriculture.

The Mini-OTEC is scheduled to be in operation fairly soon. It's a joint project of Lockheed, Dillingham, the State and the County, and its purpose is to prove that the OTEC concept does indeed work. The modern system has really not been built. This will be the first modern operation. The next project that will get underway is the so-called OTEC I, which is a very massive program. Just as an example, the Seacoast Testing Facility is something on the order of 6 to 9 million dollars, Mini-OTEC is something on the order of 1 to 2 million dollars, and OTEC I is on the order of 40 to 45 million dollars. Its basic purpose is to test 1 megawatt electric heat exchangers for the OTEC system.

Biomass energy is something that most of you are probably familiar with. Somewhat farther down the line is the cultivation of certain types of algae in seawater that can be stressed, under certain conditions, to produce oil. The principal investigator believes that you can get approximately 1 barrel of oil per acre per day under laboratory conditions. Another possibility is use of animal manure to produce methane gas.

Jim Brewbaker has worked a lot with a variety of haole koa, the very rapid-growing giant haole koa. It is estimated that about 1000 acres of giant haole koa could produce the equivalent of  $1\frac{1}{2}$  megawatts of electricity. Eucalyptus can also be used as wood chips to burn and produce electricity. One of the projects that's going to be undertaken, and we understand that final negotiations are now underway between the Department of Energy and a development group in Hawaii, is to produce ethanol, primarily from molasses. This is a joint project between the University, the State, Maui County, and the Hawaii Sugar Planters' Association. It's basically to produce ethanol from the molasses, and to blend this with gasoline to produce gasohol. This gasohol will be used as automotive fuel, the idea being that by using this ethanol we can reduce the amount of gasoline that's being burned. Again the funding is being shared by the federal government, the state, private industry, and the University. There are two parts: the first is pretty straightforward--one ferments the molasses in a still to produce ethanol. In order to lower the price of the ethanol, what we are trying to do is take the stillage, the slops, and try to recover two things: one is the potash, which is a fertilizer that the sugarcane needs, and the other is animal feed that comes from yeast. The idea is to try to find ways that are economical and feasible to permit us to reclaim the potash and the animal feed and sell them to recover some costs. This is the research part of the project. There happens to be an old rum plant that used to be part of the Seagram's subsidiary on Maui. When we get enough information, the plant will be renovated, and we will produce ethanol there. We will then be able to blend it with gasoline and sell it as gasohol.

Wind energy is something that you are familiar with. One of the projects that's been underway for the past few years, and which puts Hawaii well ahead of the rest of the U.S., is that the Department of Meteorology at the University has been, as they call it, "wind prospecting". They've been looking for good wind sites, using balloons, acoustic sounders (with which they're bouncing acoustic energy off the lower atmosphere), in order to get some idea of what the wind profile is like over much of the state. Various types of windmills are already being used. The Savonius rotor is simply an oil drum cut in half and offset, and used to pump water. A project that the Hawaiian Electric Company is undertaking is one in which the Department of Energy is going to provide a 200 kw windmill turbine generator. This will probably be placed on Oahu, at Kahuku, and will be tied into the Hawaiian Electric grid. One of the possibilities is that there are a couple of private companies that are raising private capital, and they are interested in setting up a wind farm, probably on Molokai. They plan to sell the energy produced by these wind farms to Molokai Electric, using the Command Aerospace Unit. The Boeing unit will take 16 rpm, and these are capable of generating 2500 kilowatts.

# County of Hawaii's Energy Self-sufficiency Program

By

Y. Hahn, Director

Energy self-sufficiency is years away. Why? First we must look at the current use pattern. It is composed of:

- 1) The mobile sector
- 2) The stationary sector
  - a) residential use
  - b) commercial industrial

Then we must project energy use by sector using the following set of assumptions:

- 1) population dynamics
- 2) conservation, ethics and policy
- 3) the price of conventional fuel
- 4) the availability and price of alternative energies before 1990
- 5) economic growth projections

With estimations for each of these factors we can project energy demand and supply to 1990. Each factor has three possible projections: optimistic, moderate and pessimistic, resulting in a differing outcome. Geothermal energy is the first alternative energy resource to be developed and thus will be the test case for all the rest. Our community is learning on this one case for all the others.

Q: What is the impact of less federal subsidy for the sugar industry?

A: Bagasse may become as valuable as the sugar. The price of wood chips, for example, is rapidly approaching the point where it has more value here than exporting it to Japan for paper production.



## Geothermal and the Electric Company

By

Dan Williamson, Hawaiian Electric Company, Hilo.

We in Hawaiian Electric Co. are enthusiastic about developments in geothermal energy and think that it may contribute the most after bagasse to Hawaii county's energy future. Helco, Hilo will maintain the turbine at the Puna well under RCUH for the first two years. In this time we hope to assess the unique problems there are with geothermal E.

Some foreseeable obstacles to commercialization of geothermal from the utility standpoint are:

- 1) The extent and life expectancy of the resource. This is the same kind of question we would ask about any Energy-resource.
- 2) The reliability in an active volcanic area.
- 3) Resource ownership
- 4) Environmental problems
- 5) Social problems

A public utility must need be conservative since its major goals are to provide enough energy to consistently meet demand and to provide it at the lowest possible cost. HELCO may not be able to prevent cost increases, but wants to keep them as small as possible. HELCO wants to explore all the alternative energy sources and plans a wait and see attitude. We see our role as a consumer advocate in the development stages of geothermal power. We are optimistic that geothermal power will play a large part in Hawaii's future.



THE IMPACT OF GEOTHERMAL DEVELOPMENT ON  
THE LOCAL GEOLOGY

Tom Casadevall  
Dallas Jackson

USGS-Hawaii Volcano Observatory  
Hawaii Volcanoes National Park

In several areas in the world there are geothermal fields which are located on very active volcanoes, and, as you can imagine, there are a number of inherent dangers in working on active volcanoes. The situation I'm most familiar with happens to be the Krafla situation in Iceland, where we've been involved in a program of research trying to monitor Krafla activity.

The Icelandic government in 1974 and 75 made a decision to install a 60 megawatt power plant in the Krafla caldera. It so happens that the power plant is built directly over the 1729 eruptive fissure. In December of 1975, just after initiation of the construction at Krafla, the volcano became active once again. In 76 they took delivery of two 30 MW turbines. Since that time the volcano has had seven different periods of activity, either actual eruptions or simply seismic crises--intrusive events. In addition, the character of the geothermal fluid has changed remarkably. It's gone from a system which was initially free of carbon dioxide to one in which carbon dioxide is a major component of the gas. Fluid chemistry has changed, and temperatures of the wells have changed. In September of 1977 there was an actual eruption through one of the geothermal wells. About a hundred cubic meters of lava erupted through one of the bores. So, there are problems with geothermal facilities on active volcanoes. There are things you have to be aware of and think realistically about, particularly, for example, from HELCO's point of view, in terms of calculating a hazard replacement cost.

The HGP well is located on the east rift of Kilauea Volcano. The lower east rift has erupted four times since 1790--1790, 1840, 1955, and 1960. In 1884 there was a minor submarine eruption that occurred just off Cape Kumakahi. The wellsite itself is set just to the southeast of the 1955 lava flow.

The next speaker will be Dallas Jackson, and he's going to discuss in more detail the geophysics and geology of the wellsite itself, and Arnold Okimura, who is in charge of the deformation program at Hawaiian Volcano Observatory, is here, and he'll be available to answer any specific questions about deformation and subsidence in the area. At present Dr. Richard Moore of the USGS Volcano Observatory is in the process of mapping the geology of the Puna area. Dick Moore couldn't be here today, but I'm sure he'll be available to answer any specific questions people might have regarding the wellsite or the local geology. There's another geologist, Robin Holcomb, who's been remapping the entire Kilauea Volcano, and who's been very active in dating the activity on Kilauea. Robin's found that about 90% of the surface of Kilauea is covered by lavas that are less than a thousand years old. About 80% of the surface is covered by lavas that are less than 500 years old.

Now Dallas will give a short presentation, and then we'll close by voicing some geological and geochemical questions related to the wellsite.

Dallas Jackson

One thing I should say is how the Survey got involved in the siting of the HGP-A well. We didn't work directly on it, but the University of Hawaii (HIG) came to us and asked for advice because we had been working in the area for years and had a certain amount of knowledge. We did have level lines across the highway, across Pohoiki Road, across Highway 13, and in 1973 and 74 a geophysicist at the Observatory, Charles Zablocki, had been mapping self-potential anomalies on some of the volcano. All of these anomalies had proved out to be associated with a heat source at depth. HIG was doing electrical-geophysical work, and they approached us and asked if, as a cooperative project, we would help them map the self-potential in the Puna area.

HIG and the USGS found two major anomalies in the Puna area, one high of 300 millivolts, and the other where the 1955 flows cross the Pahoa-Kaimu highway. The other geophysical techniques that were used at the time didn't come out with any kind of a bullseye pattern for drilling, but the S-P did. Since they thought it was related to some sort of a heat source at depth, although no one knew how deep it was, they decided that this was the best area, based on the anomaly and also on a number of earthquakes that occurred in that very area over the years. The S-P anomaly falls right over the 1790 vents. There was practically no anomaly on the 1955 vents. We thought for many years that, at the summit, earthquake swarms are related to magmatic activity, so we thought that would probably also apply somewhat to the choice of where the wellsite would go. There's evidence now, which I think is somewhat compelling, that this zone of earthquakes here may not be related to magmatic activity but could possibly be a transform fault that lies across the rift.

Tom Casadevall

Some of the geological and geochemical questions that these points raise regarding the wellsite will be more specifically addressed by Don Thomas and the Siegels. These concern, first of all, hydrogen sulfide emission. Is it a health hazard? Second is mercury emission. Is it a health hazard? Third is disposal of the effluent. How is this done now? Is it done through lava tubes, and if so, what implications does this have for the down-rift terminus or makai terminus of lava tubes? What are the effects of the well on local water supplies? This is probably minimal, because most of the water in the area is from catchment and not from water wells. But if it is from catchment, this raises the adjacent question: what influence does the well outgassing have on rainfall? Is there an acid rainfall problem here? This will have implications for local agriculture as well as residents.

What about the problem of subsidence of the land due to withdrawal of the water? What about seismic activity due to water withdrawal? We've already seen that this is indeed a seismically active area, especially in the area of the well. Will this seismic activity be enhanced due to withdrawal of the water or production from the well? What about the possibility of initiating eruptive activity? In Iceland there are a lot of local residents in the Krafla area who are pretty well convinced that the reason the volcano suddenly became active again is that they've been drilling so many geothermal wells. There's a cause and effect relationship here that's kind of unclear.



What changes in the character of the fluid, the chemistry and pressure, might occur due to production from the well and also due to volcanic activity in the area? In Iceland it's very clear that the onset of volcanic activity has changed the character of the gases and the fluids from the well. Finally, what about the mobility of the unit; that is, the "breakdownability" of the plant? One solution they've found in Iceland to soften their losses in the event of an eruption is to break down all mobile equipment and airlift it out. They have some very large Russian helicopters there which have a very large lift capacity. Has this been considered in the design of the local plant?

These are just some questions that come to mind.

#### QUESTIONS AND COMMENTS

Q. There's been a past discussion about the possibility of diverting a lava flow. Could you comment on that?

A. There is a lot of discussion about diverting lava flows, for example, diverting lava flows from the Hilo area. They've got a plan in Iceland for diverting lava flows from the vicinity of the Krafla plant. There's also some debate as to how successful previous attempts at diverting lava flows have been. It's a pretty emotional issue. I'm not aware of any plans in the Puna area to divert lava from the HGP wellsite. There were efforts during the 1955 activity to divert lava flows and some of you may have seen the barriers on the road between Opihikau and Pohoiki. To my knowledge they weren't very effective. The lavas either stopped of their own accord or changed course before they actually had a chance to test the barriers.

Q. Thirty years seems to be cited as the lifetime for a plant, and I was wondering in this area what the chances are of another eruption within that time.

A. That's a real good question...something I hope that Dick Moore and Robin Holcomb may come up with at the conclusion of their studies. If you look just at the frequency now, we've had an eruption about every 50 years, on the lower east rift of Kilauea...1749, 1790, 1840, 1884, 1955, 1960. And just uprift, just mauka of the site, of course, was the 1977 eruption. The area is a potentially active area, and if you believe Robin Holcum's chronology, that part of the volcano especially has a very young surface.

Q. Is there any experience or information on building in a rift zone on piles, building the plant on piles?

A. Actually building on piles? Not that I know of. The diatomaceous earth plant that somebody mentioned earlier is also built smack dab on a rift of Krafla Volcano, actually the mid-Atlantic Rift, where the Atlantic Ocean is actually opening. The '75 rifting event added about 60 centimeters to their entrance foyer. They actually just came in and added bricks to the foyer. The diatomaceous earth plant hired some engineers from Sweden who came in and built a lava barrier completely encircling the plant, and they hope this will divert the lava. The entire diatomaceous drying plant is built on 1724-1729 lavas, and a lot of the power plant--the cooling towers especially--at Krafla in the crater itself are also built on 1729 lavas.

# THE IMPACT OF GEOTHERMAL DEVELOPMENT ON THE NATIONAL PARKS OF HAWAII

David Ames  
Superintendent, Hawaii Volcanoes National Park

My participation in this workshop is possibly very simple, because National Parks, by definition and by law, do not have any commercial development, such as geothermal power plants. So we don't have any direct comments to make along that line. We do have concerns, however, with any kind of development adjacent to parks, or geothermal energy plants that might be located along the edge of the park, or near the park. We want to ask a lot of questions, and many of these are the same things that Tom Casadevall mentioned. We would question what would the emissions be, what would the effects of the various emissions and their contents be on air quality. What would the effects be of noise near the National Park? What would the effects be of development that would occur as a result of an increase in cheaper or more available electrical power?

Hawaii Volcanoes National Park, like many other national parks, has enjoyed a kind of natural buffer zone around the park of undeveloped land or partially developed land, just by pure accident. A lot of national parks are in areas that are already surrounded by ranch land or National Forest or farm land, or sparsely developed areas that, in effect, give a kind of buffer zone around the park. And since this national park has the source underground of a lot of the geothermal energy, it makes sense that if it does work out to be economically feasible, the plants will be located closer and closer to the national park. Any subsequent industrial development, such as we read about in the newspaper last night about Pahoa turning into an industrial giant--a mini Gary, Indiana--what happens if something like that occurs closer to the national park? If a lot of electrical power is generated, where do the transmission lines go? Do they go near the park, do they want to go across the park?

What are the effects of increased seismicity? What happens if the volcano is changed in its plumbing in the area of this new plant, which seems like a lot of miles from the national park, but on the scale of the plumbing of the volcano, it's fairly close. What if it does have some effect on the volcano, if it possibly might cause an additional eruption, or the lack of eruption in the national park? And what about the disposal of the brines they were talking about? Where do all the major and minor elements go? Will there be disposal such as Tom mentioned that eventually gets into coastal waters? Unfortunately, I don't have any answers to these, but I don't think anyone else does either.

These are the kinds of questions that the National Park Service would raise. This morning, cultural conflict and changes in lifestyle were mentioned, and if it all comes down to those being changed, or if there are some other environmental changes, then the very purpose of the National Park is being served, albeit in a sad sort of way. It becomes, then, a museum or a repository of what once was.



However, when you think of the alternate methods of generating electric power, and having just come from a national park in the southwest that is bracketed by two 350-megawatt coal burning plants, which had massive detrimental effect on the environment, especially air quality, geothermal energy appears rather clean here. Very clean, as a matter of fact. And the only questions we have are concerned with these vague unknowns, because we are dealing with a new technology.

#### QUESTIONS AND COMMENTS

Q. How many acres does the National Park have?

A. 220,000 acres. Most of the rift zones extend well outside the park; however, we tend to have the upper portions of most of them, though not all.

Q. It seems to me about ten years ago there was some drilling in the park.

A. Yes, there was some drilling for various study purposes. I think the information from the drilling that the Geological Survey and the other contractors have done has to do with a wide variety of fields, including geothermal.

A. (from Tom Casadevall) George Keller from the Colorado School of Mines, and under funding from the National Science Foundation drilled a 4300 foot well just to the south of Halemaumau, within Kilauea Crater. The purpose of this well was not to exploit geothermal resources; it was essentially to explore the geological character of the volcano, that is, what percent of the volcano is made of clastic materials, what percent lava flows, and how do these characteristics affect geophysical characteristics of the volcano...information to be used later on in exploring for resources along the rift zone. The purpose of the well was never to exploit a resource. One of the things they did measure was heat flow from an active volcano. They also tried to do water chemistry and chemistry from the rocks they found in the well. They also did a lot of geophysical measurements in the well.

There was also some drilling in Kilauea Iki. Kilauea Iki, as you know, was filled in 1959 by about 375 feet of lava. The Survey began drilling in Kilauea Iki in 1960. One of the purposes of the drilling was to find out exactly how does a thick lens of molten lava cool. These, again, were research wells. The latest drilling concluded at the end of February of this year, in which they found molten lava at a depth of 173 feet. These are research wells, and we have no intention of trying to exploit geothermal energy within the park.

(Ames) That goes back to one of the main purposes of the national park, as a center for research. Much of the research could have commercial application, but not in there.

Q. National parks are supposed to maintain Class 1 air. Do you do any monitoring, or how do you make sure that this is maintained around the boundaries?

A. Well, this is a problem. We don't do any monitoring. I know that in national parks on the mainland--I just came from Petrified Forest National Park--in that park they did have extensive monitoring, and other agencies were doing monitoring, along with the power companies, because of all the power plants immediately adjacent to the park. Two were adjacent to it on either side of the park, so that whatever way the wind was blowing, you'd get coal smoke... not to mention many massive power plants that were in that region. We're up

against Halemaumau! Most of the pollution we find is natural pollution--that's what we're in the business to preserve!

Q. Has there ever been an attempt to establish baseline parameters, say for atmospheric quality in the park? If not, wouldn't pretty soon be a good time to establish that data, with the prospect of perhaps a mini-Gary, Indiana on the horizon?

A. Absolutely. That kind of baseline information is needed.

Q. Whether it's realistic in an island situation, though, where the whole block of air is moving away, and there's nothing coming in to replace it...

A. (Don Thomas) Another thing, the idea of a baseline for a volcano is probably impossible...no such thing exists. The baseline for the pollutants it puts out varies from day to day, from year to year. Five years ago there was probably twice as much pollutants being put out by Halemaumau as there are now, so there really is no natural fixed baseline: what we measure today may not necessarily mean anything five years from now.

(Ames) I know the years I was living in Kona were very active years for the volcano, and the smog was terrific, though it was all natural smog from the volcano.

Q. Along the same line, you implied that it was not feasible to do this in an area such as Hawaii Volcanoes National Park because of the fluctuations in the quality and quantity of what are characterized as pollutants. I wonder if it wouldn't be worth something to science, and also as baseline data, to have a long-range monitoring experiment to characterize these pollutants over the longer term...

A. (Tom Casedevall) Since February of this year we've had a continuous air quality monitor at the Observatory. This experiment is being conducted with National Science Foundation funding by Jack Winchester and Mike Darcy of Florida State University. They also have monitors at Mauna Loa Observatory, American Samoa, Point Barrow, Alaska, South Pole...so we do have a monitor now at the Volcano Observatory. In addition, they're going to be coming out this summer and setting up several of these monitors in the vicinity of the volcano, both upwind and downwind from the volcano. They take an air sample that is sucked across a thin mylar-type of film, and this is brought back to a reactor. It's bombarded with protons, and each element gives off a characteristic spectrum following bombardment. In this way we can tell what the ratios of these elements are--what the absolute abundances of the elements are on an hour by hour basis. These are called "streaker experiments" because you use a two-week-long film, and the suction cup essentially streaks down the film. The timing mechanism is quite precise, so we know hour by hour what happens. We can correlate this with weather observations that we make, such as rainfall, wind direction and wind speed, temperature, humidity, barometric pressure. So there is, in effect, air quality monitoring going on, although we don't think of it as monitoring air quality. We're looking for changes in the air, trying to tie it in with changes in the activity of the volcano, changes in atmospheric conditions, etc. We hope to continue this on a long term basis, at least for the next several years, to establish a baseline.

THE IMPACT OF GEOTHERMAL DEVELOPMENT ON  
THE OCEAN'S BEACHES, FLORA AND FAUNA, ETC.

Keith Chave  
Professor of Oceanography  
University of Hawaii at Manoa

Because I thought everyone was going to be very serious today and talk about dollars per kilowatt hour, and because Don Thomas is going to talk tomorrow particularly about fluids and their potential effects on the environment, and because Bobbie Siegel said to come over and talk about geothermal and the oceans, today I want to talk about some natural geothermal energy in the oceans and its effect on the environment.

The area of interest is in the eastern tropical Pacific Ocean on the equator, between the Galapagos Islands and Ecuador, at a depth of  $2\frac{1}{2}$  kilometers below sea level. In this area, known as the Galapagos rift, seawater circulates deeply into the hot lavas of the sea floor, where it's heated to several hundred degrees Centigrade, and then returned to the ocean by a series of vents on the sea floor. By the time it reaches the ocean it is cooled to 60 degrees Centigrade or less. The volume of hot water leaving the vents is very large, and chemically the waters are not unlike the waters from the HGP-A well. Rich in silica, hydrogen sulfide, carbon dioxide, manganese--although most metals are quite low in concentration, having precipitated out as sulfides with the hydrogen sulfide. So what are the environmental effects of this natural geothermal experiment?

Diving in the research submersible "Alvin", scientists have observed and collected vast numbers of "exotic" animals in this normally biologically barren, dark, cold region,  $2\frac{1}{2}$  kilometers below the sea surface. In fact, the names given to these vents on the sea floor are such as "Garden of Eden", "Dandelions", "Clambake", etc.

What has been found on these vents on the seafloor, these natural geothermal experiments, are clams up to 15 centimeters in length, mussels up to 15 cm in length, opihi, tubeworms up to 37 cm in length and 5 cm in diameter, 7 species of exotic fish, 2 species of crab, some very strange jellyfish, and various sea anemones, none of these things occurring naturally on the deep sea floor, most of them new genera or even new phyla of organisms.

The natural geothermal experiment on the Galapagos Rift is a great and beautiful environmental success; and I don't see why the geothermal experiment on land, in Hawaii, if properly managed, should be anything else.

#### QUESTIONS AND COMMENTS

Q. What do the animals feed on down there?

A. Of course there are no plants down there, so the entire food chain is based on bacterial reduction of hydrogen sulfide, and all the organisms that live there are filter-feeding organisms that filter out these bacteria. So the hydrogen sulfide in this system is good stuff.



Q. Has there been any experimentation with geothermal aquaculture in Hawaii?

A. (from the floor) In the Raft River geothermal area there is an experiment going where they are raising fish which are intended for human consumption, and they're getting incredibly high growth rates. They are investigating possible concentrations of heavy metals.

A. (from the floor) I had the opportunity to talk to someone from the Raft River area, and he said that some of the shrimp that they're also raising are pretty tasty!

Q. What's used at that catfish farm? Does he use a heat exchanger?

A. (from the floor) It's direct heat.

Q. He sells those fish all over. Is there a study on the toxicity of that geothermal application?

A. (from the floor) The fish farm at Long Valley--the whole reason it's there is that the cold water is modulated by the geothermal springs. The fish grow very well.

A. (from Barbara Siegel) The water at this well at this time is equal to agriculturally acceptable but not drinkably acceptable, which means that it could be used for irrigation and general farming. There are a couple in New Zealand that are so full of arsenic that I think you could wipe out all of Christchurch without any trouble.



THE STATE OF THE ART IN GEOTHERMAL DEVELOPMENT---  
ENGINEERING CONSIDERATIONS

William Chen  
Site Engineer, Hawaii Geothermal Project

I am an engineer, and engineers do design work. The first thing we ask is: what is the allowable standard? Be it set by EPA, County, State, or OSHA, we take that standard, and we go to our drawing boards and design for three things: technical feasibility, safety and economics. If none of them are feasible, either the standard must be changed or we abandon the project. If technically it's feasible, and it's safe, we look at the cost. If the cost is too high, we either reset the standards, accept it and go ahead, or abandon the project. If the cost is reasonable, we proceed. You tell us the standards, and we will tell you whether or not it can be done. Those are the engineering considerations.

Let us look at the three phases of a geothermal development. We have drilling, the testing phase, and the construction and plant operation. In all of these phases we have environmental concerns. During drilling we have noise pollution, we may have dust, certainly we will have a visual effect, and we have safety considerations. During the testing phase, we have noise, we have effluents--gas, heavy metals--and wastewater disposal. During plant operation we will have piping problems, because you have to get the fluid from the wellhead to the plant. You still have noise, odor, and wastewater. I would now like to walk you through the wellhead generator that we have planned, and talk about the specific standards that were imposed, or that we select to use, and how we are going to achieve them.

This is a very fast chronology of what has happened: in 1972 we organized, 1975 we started drilling, April of '76 we completed down to 6450 feet, cased and cemented down to 2230 feet. We have three casings: an anchor casing, a surface casing, and the production casing. There is a tremendous amount of weight, so there is no danger of the well becoming wild. The first flashing was completed in July, 1976, and we did a 42 day test from March to May, 1977. We found out that in the reservoir, flashing is in the formation. We do have unstable pressure at reduced flow (we can only cut the flow back by about 70%). The fluid is high temperature, 350 degrees Centigrade downhole, with about 60% of steam and 40% of water. The stable flow is around 100,000 pounds per hour, with about 60,000 pounds of steam and 40,000 pounds of water. We have noncondensable gases, the biggest nuisance encountered being hydrogen sulfide. There are dissolved solids in the water, and the one that will give us the most problems probably will be silica.

The objective of the wellhead generator project is to determine the technical feasibility of baseload electrical production, to collect data on how such a system can be built, to study economics, and to perform long term reservoir testing. What we are trying to deliver is a condensing generating system with full environmental control.

The site that we have is 4.1 acres adjacent to the wellsite. It is on the 1955 lava flow. We do have to look at the risk of lava flows. Dr. Macdonald, in an internal document, has said that the chances of a lava flow at that site within the next 30 years, which is a reasonable lifetime for the plant, is about 1%. It's still hot. We have decided that the best way to protect the plant

from a lava flow is to make the major equipment portable. So in the case of an imminent lava flow we can unhook all the piping, put the major pieces of equipment on a truck, and haul them away. We also have a wellhead protection plan. We don't want the wellhead, the valves, destroyed or melted by the lava flow. We will build a barrier around the wellhead, fill it with cinders, place a lid on it, and let the lava flow around it, over it, etc. Later, if we want to use it again, we can dig it out.

We will collect all the environmental data and all the reservoir data. Finally, there will be a visitor center so that people can see how a geothermal plant works.

The project is organized by three principals: the State of Hawaii, the County of Hawaii, and the University of Hawaii, contracted with the Research Corporation of the University of Hawaii. We have selected three subcontractors: the power plant engineering is by Rogers Engineering of San Francisco. The environmental monitoring contract is with Environmental Analysis Laboratory, and the reservoir engineering is contracted to the University of Hawaii, Hawaii Geothermal Project. When the plant is built, Hawaii Electric Light Company (HELCO) will be the contractor to operate and maintain the plant.

The three main environmental considerations are wastewater discharge, hydrogen sulfide, and noise. For hydrogen sulfide, we adopted an EPA standard which says that, wherever steam is released (unused steam), the maximum concentration of hydrogen sulfide is between 20 and 40 ppm. If the steam is going to be used to generate electricity, the maximum  $H_2S$  that can be released is 200 grams per megawatt-hour generated. This means approximately 93% removal of hydrogen sulfide at the wellsite.

The EPA standard for noise is less than 65 dB on the A scale at  $\frac{1}{2}$  mile radius. For wastewater, the Department of Health feels that after removal of silica from the fluid, we can surface percolate. In general, in a large developed field, wastewater is not surface percolated, but is reinjected into the reservoir.

As for operational considerations, we are building a utility standard plant which must be designed for reliability, integration with the HELCO system, and since the operation will be by HELCO, we will adopt all of their standards.

I will now describe the basic steam supply system. The fluid will come out of the wellhead and will go to a separator to separate the steam and the water. 99% of the hydrogen sulfide will go with the steam phase. The steam enters a valve box, which is buried underground. Any big change in pressure usually creates noise, and since the main pressure change is in the valves, they will be buried to reduce noise.

The steam normally will go to the turbines. In case the main hydrogen sulfide abatement system fails, the steam will go into a secondary treatment tower, in which we will use hydrogen peroxide and caustic to take hydrogen sulfide out. It will then be vented to the atmosphere. The hydrogen peroxide



system is very expensive. For example, this August we will be conducting a two-week test, using hydrogen peroxide for  $H_2S$  removal. The chemicals alone will cost \$92,000, and the system we are using costs \$163,000. So it will cost over \$10,000 a day just to treat the hydrogen sulfide.

The steam that comes from the separator will go through the turbine, and we plan to use enough steam to generate 3 megawatts, or 3,000 kilowatts, which will satisfy the electrical needs of approximately 3,000 people. The electricity produced will be absorbed into the HELCO system. The spent steam will go to a condenser, where the steam will cool down to about 180° F. The gas will be ejected to the hydrogen sulfide abatement system. The condensed steam will then be piped to the cooling tower basin. We use the evaporation of steam to cool the cooling water. Approximately 25,000 pounds per hour of cooled vapor will be going into that system. Cooling tower water will combine with water from the separator, and both will enter the cooling pond. In the pond, the water will be held for approximately one hour, which will allow 99% of the silica to precipitate out (which will be harvested). The rest of the water will go into the percolation pond, and percolate down into the subsurface.

In the main hydrogen sulfide abatement system, the condenser gas combines with air in the presence of a propane pilot light, and it is burned. On burning, we convert the hydrogen sulfide into water and sulfur dioxide. Cooling water will be used for quenching, then the water goes into an absorber stack, where we will circulate a very weak caustic solution. Practically all of the sulfur dioxide will be absorbed into the caustic solution; then it will also go to the cooling tower and then to the percolation pond.

The artist's conception of the generating plant shows the current wellhead structure with the two towers, a turbine building and cooling tower, and a visitor center.

#### QUESTIONS AND COMMENTS

Q. Have you calculated how many tons per day of sulfur dioxide you're going to produce? Or how many tons of  $H_2S$  per day do you expect to be given off?

A. I think it's about 900 pounds of hydrogen sulfide.

Q. You mentioned in August you're going to have a 2 week test using hydrogen peroxide on the hydrogen sulfide. What is the purpose of that test if you don't intend that process to be a permanent part of the operation?

A. All of the tests we have conducted have used the whole flow, not separated. But in the test in August we're going to separate it into liquid and steam and make more accurate flow measurements. We know the odor is there whether or not it's separated. In order to do the 2 week test we made an agreement with the residents that we will not conduct any extended testing without abatement.

Q. What are the chances that there could be some sort of a valve problem that could result in an explosion or a blowout?

A. Every valve system that we have has 2 in series. We never use the bottom one for any dynamic situation. If we're going to start the well flowing, we open the bottom valve all the way, then we open the top valve to let the fluid

flow. When we shut the well down, we shut the top one first, then the bottom one. We use the top valve to take all the abuse, and we always have one extra.

Q. Is that a manual system or a remote system?

A. It's manual. It can be motorized, but someone has to be there. All valves right now are rated at 2260 pounds of wellhead pressure. The highest pressure we have ever recorded is 905 pounds. Normally a valve rated at 2260 pounds has been tested under static conditions up to 3000 pounds. The chances of a blowout are always there, but we think about all the safety precautions we can to protect ourselves. Each big valve costs about \$10,000. We think that two valves will make it safe. I've only heard of one situation where a valve failed, in Iceland. They had an underrated valve, and they did not want to close it because they were afraid that too much pressure would build up and the valve would break. So they cracked the valve and let it blow. The valve was eroded off; the casing was also eroded off, and it blew a 75 foot crater. But after 3 days, it sealed itself.

Q. You have a very conservatively designed system. How does it relate to the system at the Geysers, where about two years ago they had a well that had been drilled and closed in, and one day just popped. Do you know the history of that?

A. It was a casing fracture...there was a fault and subsidence. There's one more valve blowout that I know of. In Indonesia, a well blew out and killed three people who were working on the site. It was a valve manufactured in Belgium in 1920 for oil fields. The Indonesians refused to allow the safety valve on the stem to let go and bleed off the pressure inside the valve stem.

Q. When you scrub out the  $\text{SO}_2$  and you produce a sludge, how much of that will there be?

A. It's not a sludge. It's a clear liquid.

Q. You were speaking of harvesting the silicates, and what is that process? What are you going to do with it?

A. In the cooling ponds there is a series of baffles to allow the water to go through. The silica will attach to these baffles. There will be two ponds, and only one of them will be used at a time. When the silica is starting to settle out and attach to the baffles, we will drain the water into the other pond, then go in and just break the sheets off the walls and discard it. It's just sand.

Q. What is the fluid temperature when it's exhausted from the turbine? Is it possible to use that heat for direct heat applications rather than having to go through all the elaborate cooling system?

A. The temperature is about 180 or 190 degrees F; that's the water that exits from the condenser. After this we do not cool it any more; it is put into the cooling tower pond, and at that point it is 180° F.

Q. Can you do better than 93% removal of  $\text{H}_2\text{S}$ ?

A. Yes, with hydrogen peroxide, but normally we will not use this. We also will not be injecting it into the fluid phase which contains a small amount. When the water passes into the silencers it is still very hot, and there is some evaporation and escape of steam from there.



We have probably the most conservative plan in the world for removal of non-condensable gases. We not only have downstream  $H_2S$  removal which takes care of  $H_2S$  during normal operations; but if the turbine stops and we have to vent the steam, we have the hydrogen peroxide system that gives you the same  $H_2S$  removal you would have during normal plant operations. In case we cannot get the turbine back on the line in 48 hours, we will shut the well. Any problem should be able to be solved in that time, and that is the supply of hydrogen peroxide we have on hand, to treat the steam while we take that turbine out of the line. We have made sure that hydrogen sulfide abatement is going on all the time the well is open, whether the plant is operating or not. Also, in the condenser, we are using a so-called surface condenser, not a normal contact condenser, and that adds another \$300,000. So the total environmental consideration in the plant adds about a million dollars.

Q. What are the cooling towers constructed of, and how big are they?

A. They're made of wood, about 35' tall.

Q. What kind of silencers do you have?

A. The silencers that we have on the site right now don't work very well. Sound is reduced from about 125 to about 95 dB at the site. It doesn't work that well because of the high steam to water ration. When we use it later on we will have 100% water.

Q. I understand that at the Geysers they have a sort of rock pit silencer.

A. At the Geysers they have 100% steam, which is very different. In New Zealand where they use a system like the one here, they have 20% steam, and it's very quiet.

Q. About the percolation pond...could you give a little more information about the volume of water per day, and the temperature of the water, the size of the pond, the percolation rate...?

A. We can look these numbers up later. In the artist's conception the size of the ponds is not correct. I think they are actually quite small, about 20 by 20 feet. The volume is not large, something like 60 gallons per minute.

Q. Are there any kind of safety standards concerning valves?

A. Oh yes. In addition to environmental standards there are all sorts of other standards---building standards, etc. Engineers build by the book.

Q. What percent of the total cost, then, is going to environmental considerations?

A. The plant itself will cost about 5 million dollars. About 25% of the cost is going to environmental controls.

THE STATE OF THE ART IN GEOTHERMAL DEVELOPMENT--  
THE GASES AND EFFLUENTS

Don Thomas  
Hawaii Institute of Geophysics,  
University of Hawaii at Manoa

What I would like to do this morning, for the people who aren't familiar with geothermal, is give a general overview of what geothermal effluents are, where they come from, what they can do, and then speak specifically about the Hawaiian geothermal well and what we are going to do about the effluents there.

The first question that should be addressed is, where do the effluents come from? What is in the water, what is in the steam? Generally, geothermal fluids have dissolved salts out of the rocks, and these salts cover a wide range of elements. We have the standard salts, such as those found in ocean water: sodium chloride, calcium carbonate, magnesium. And these are all fairly benign salts, things you can swim in. They have no ill effect unless you get a tremendous overdose. An analogy in continental terms, as far as geothermal fluids are concerned, is hydrothermal mineralization. What we have in Hawaii or in hydrothermal systems in general is actually a young "gold mine". The groundwaters concentrate the salts from the rocks, and then, at some later point, deposit them in a much more concentrated form. To go through a list of all the elements that are dissolved, you practically have every element that's on the periodic table. A few of the important ones are:

The gases: A whole series of different types of gases are dissolved.

carbon dioxide

hydrogen sulfide (this is the very familiar rotten egg smell)

sulfur dioxide (something you can smell at Kilauea)

hydrogen

methane

carbon monoxide (which is highly toxic--and in some areas of continental hydrothermal mineralization, this is present in fairly high concentrations. In Hawaii it's very low.)

ammonia (also present in continental terrains. In Hawaii, again, it's very low.)

Dissolved solids:

sodium chloride and magnesium chloride (again, your standard ocean water salts)

Some of the less benign salts are some of the transition metals. This would include:

copper, lead, cadmium, mercury, arsenic and thallium.

(These are the transition metals you would find in mines and hydrothermal deposits on the Mainland.)

The next question that should be answered is: what can they do? What effect do they have on the ecology of humans, flora, and fauna near a hydrothermal system? The first order is, they do absolutely nothing; they are very benign things. Nitrogen and argon are very inert gases that come out.

You really don't have to worry about those at all. They do nothing. A little bit further up the scale, it's possible to contaminate water supplies with salts if they are dumped directly into the water supplies, or if they naturally enter the water supplies, which they often do. You will find saline groundwaters--these are waters that are unsuitable for drinking or many other uses. They can be noxious--and hydrogen sulfide is a good case in point. It can be very bothersome. (For myself, I don't mind the smell of hydrogen sulfide at all, but other people can find it very objectionable.)

They can make you sick. I'm sure everybody has seen the old Hollywood Westerns, where the cowboy comes up to a spring, takes a drink, and immediately keels over. This is an example of a hydrothermal spring that has been contaminated with something like arsenic or lead, which are quite toxic and can kill you.

On the other side of the coin, geothermal effluents can also light your home and cook your food, because of one very important hydrothermal effluent: steam. Another benefit that can be derived from hydrothermal minerals is that they can be recovered. Sulfur dioxide is actually a marketable material out here. Sugar companies do use sulfur dioxide in the clarification process. In some places on the Mainland, the concentrations of certain transition elements are so high that there has actually been some talk of recovering these--of actually using the geothermal areas and their effluents as a mine, to do liquid mining of the heavy metals.

Getting into the specific case, looking into the geothermal effluents that we have in Hawaii, we have a brine. It's actually a very low concentration brine. We have some salts dissolved in the geothermal well fluids. There is sodium chloride, the standard sea salt, and we believe that this is actually derived from seawater. Seawater enters the vicinity of the well at a fairly shallow level, is heated, and then comes to the surface. There's not too much to worry about as far as that's concerned. Sodium concentration in the well waters is about 1480 parts per million (milligrams in 1 liter of water). By comparison, the concentration in seawater is about 10 times what we see in the well. The potassium is somewhat higher in proportion, so we can see that we are actually mining some of the potassium out of the rock. Calcium is also proportionately somewhat higher, but again, well below seawater concentrations. We have a very small amount of magnesium and chloride. Again, these are very benign, unharmed things, so we don't have to worry about them.

Of more concern are the heavy metal concentrations. Mercury in the geothermal waters is about .41 parts per billion. To give some idea of what scale this is on compared to some things that you're familiar with, we figure that mercury will be produced at HGP-A on the order of 1.4 grams per 24 hours. The maximum allowable standard for a coal powered plant is on the order of 2300 grams per 24 hours. This is about 1½ thousand times what HGP-A is putting out. Another comparison is the Sulfur Bank. Sulfur Bank fumarole is estimated to put out 30 KILOGRAMS, 30,000 grams in a day. So we are on the order of 2000 times lower in mercury than the Sulfur Banks. Cadmium is a fairly toxic element. We have looked for it and cannot find it--it is below our detection limits, and other people who have done analyses estimate it to be about .3 milligrams per liter (ppm). Recommended maximum for agricultural use is about 5 ppm, a factor of 10 higher than what we have in the geothermal fluid. Thallium is less than 1 ppm, below our detection limit. Arsenic is



# CHEMISTRY OF GEOTHERMAL WELL WATERS AND GASES

## H G P - A

### ION CONCENTRATION\*

Date	Sample Description	Sodium	Potassium	Calcium	Magnesium	Chloride
4/22/77	Effluent Water During Steam Discharge	1,480	277	72.2	< 0.1	3,190
	Sea Water Composition (For comparison)	10,668	386	410	1,286	19,217

### Heavy Metal Concentrations\*

Date	Description	Mercury†	Cadmium	Lead	Thallium	Arsenic	Copper	Zinc†
6/16/78	Effluent Water During Steam Discharge	0.41	≤ 10	< 1	≤ 1	< 0.5	< 10	≈ 35

### Gas Chemistry\*

Date	Description	Non Condensable Gas Concentrations (Relative to Total Discharge)				Non Condensable Gas Ratios	
		CO <sub>2</sub>	H <sub>2</sub> S	N <sub>2</sub>	H <sub>2</sub>	CO <sub>2</sub> /H <sub>2</sub> S	N <sub>2</sub> /H <sub>2</sub>
5/9/77	Steam and Gas Taken During Steam Discharge	1,753	647	270	11	2.71	24.5

\*All concentrations are in units of milligrams per liter of water except those denoted by † which are in units of micrograms per liter.

less than  $\frac{1}{2}$  part per million. We believe that the levels of these elements are well below what could be dangerous to the populace.

I mentioned earlier that the geothermal effluent can be considered a young "gold mine". We don't have any mineable minerals in Hawaii, simply for the reason that there are not enough of these transition metals in the rocks to be concentrated by the geothermal fluids. So, in fact, we should almost expect to find much lower concentrations of the heavy metal salts in the geothermal fluids out here than what is normally seen in continental terrains. Copper is less than 10 parts per million, zinc is about 35 ppb, which is actually higher than the acceptable limit for agricultural use, but this number we have since started to question. We feel that may be an artifact of our sampling, that we contaminated the sample before we took it back to the lab. Actually, we intend to re-do all of these analyses during the two week test in August.

The gas concentrations: carbon dioxide, about 1750 parts per million, or 2700 kilograms per day. (Kilauea puts out more than a million times this much  $\text{CO}_2$  per day.) Hydrogen sulfide: about 640 ppm, or 900 pounds per day of sulfur (as compared to 100 million pounds per day from Kilauea). Nitrogen and hydrogen are insignificant; radon has been measured at 23 microcuries per hour.

This, then, is basically what's coming out of the well at HGP-A. Concentrations of most of these things are actually not much higher than what is found in the groundwaters in the Puna District below the Kilauea east rift. Another factor is that the rainfall in the area is well over 100 inches per year. We believe that the dilution of any salts in the geothermal effluents by rainwater will simply wash them out, and we won't even be able to see them, much less have any significant effect on the groundwaters in the district.

The transition elements are all below either drinking water standards or standards for agriculture. When they are injected into the ground and diluted with rainwater they will have no significant impact on the groundwater in the area.

The single most important thing that we're working on is the elimination of hydrogen sulfide from the gas phase which is coming out of the well. Hydrogen sulfide will be incinerated, as Bill Chen went into in great detail. Sulfur dioxide will be reabsorbed into the effluent and "dumped" into the groundwater. It's probable that we won't see any significant impacts on the local groundwaters of this sulfur dioxide. We will be monitoring groundwater wells downstream to see if we can detect any increase in sulfur dioxide or sulfur compounds in these groundwaters.  $\text{CO}_2$ , carbon dioxide in the gas phase, is simply going to be released into the atmosphere. It is of such negligible concentration that we don't expect it to have any impact on the environment of the area. The other gas phases are so insignificant as to be not even worth worrying about. Hydrogen will be incinerated with the hydrogen sulfide; nitrogen is totally harmless.

What does all this mean to the Puna people, and the people in Hawaii in general? Near-term development of HGP-A will probably have very little environmental impact on the Puna area. There simply isn't enough being produced, and the Department of Energy is going to a tremendous amount of effort and

expense to see to it that the plant will be an environmentally acceptable addition to the Puna area. Long term development is a lot more difficult to speak for. The elements in the geothermal effluents will probably be disposed of by deep pumping. The hydrology of Hawaii is such that we have a fresh water lens floating on seawater down inside the island aquifers. Under extensive development, where we do have a lot of geothermal water being brought to the surface, probably the best way to dispose of it will be to pump it back into the salt water where it came from. The gases, particularly the  $H_2S$ , will probably be recoverable rather than being a nuisance. We will probably be able to convert it into a form that will be useful to the sugar industry or, if there is extensive development, use it in industrial processes. It can be used in manganese nodule processing and possibly other industrial uses can be found for it. So rather than a drawback, it may turn out to be an asset.

The last thing I want to do before I open this up to questions is to try to answer some of Tom Casadevall's questions that were raised yesterday. The hydrogen sulfide emission as being a health hazard: we've gone to great extents to see to it that it isn't a health hazard. We will see to it that it is taken out of the geothermal effluents and that it isn't allowed to escape into the atmosphere. Mercury emissions: if you live in Puna, on the Kilauea slope, you're probably getting more mercury simply by living there than you would anywhere else in the state. The input of HGP-A to the total mercury budget in the area will probably be insignificant.

The disposal of the effluents: the effluent that we're producing from HGP-A will be allowed to percolate into the ground. This is a great problem in continental terrains--disposal of geothermal effluent--because you simply can't allow it to percolate down. It will contaminate the static water levels that are normally drawn upon. In Hawaii we have a unique hydrology, unique groundwater. The groundwater is continually renewed, continually washed, so that when we pump geothermal fluids into the groundwater, they're simply going to be washed away. Billions and billions of gallons of groundwater are lost along the perimeter of the island every single day, so if the geothermal effluents are allowed to percolate into the ground water, they are simply going to be swept away. The effect on water supplies: the groundwater in Puna is not used extensively because it already is contaminated by seawater, and the water that is drawn anywhere in the Puna area is drawn from a level that is less than a thousand feet below the surface. The groundwater that we are drawing on is from a depth greater than 2000 feet. So there is a thousand feet of rock between the waters that we begin to draw on and the bottom of where any public groundwater is drawn in the Puna area. I find it highly doubtful that we will see any significant impact due to withdrawal of geothermal fluids on the groundwaters in the Puna district.

Subsidence of land due to withdrawal of the water: as I said before, the groundwater below Puna is continually being lost, and continually being renewed. Although 100,000 pounds of water per hour is going to be produced from the well, probably on the order of 100,000 to 1,000,000 times more water is being put into the ground simply by rainfall in the area.

Seismic activity due to water withdrawal: there may be some microseismic activity; my estimation and the estimation of the geophysicists I have talked



to indicate that the withdrawal of water where we are taking it from would produce only very minimal seismic activity, if any.

Possibility of initiating eruptive activity: in my opinion, there is no possibility whatever. I hate to say never, but the volcanic system of Kilauea begins at the Kilauea caldera. Anything that we see in Puna is what has already come up beneath the caldera and come down into the Puna area. Initiating a release of magma at the summit caldera is such a small possibility as to be totally out of the question. I think the conditions in Iceland are much different than they are here, and I sincerely doubt that any geothermal development there had any effect on the increase in volcanic activity.

#### QUESTIONS AND COMMENTS

Q. How about changes in the chemistry of the well during production?

A. I think it probably will change. We haven't produced the well long enough to get a real handle on what is actually going to come out after long term production. We are caught in a very tight bind. It's going to cost us \$160,000 to run the well for two weeks. I would like to see the well run for a year. That way we would have a much better idea of what is likely to come out of the well after long term production. The aggregate amount of time that we have allowed the well to flow is on the order of 60 days. I expect to see a lot of changes in the well.

Q. Did I understand you to say that you will inject the things that come out in the steam back into the ground? And it won't go back down to replenish the steam that you are taking out?

A. The source of the steam that we're seeing is down about 6000 feet. The water pressure down there, simply from seawater and fresh water above it, is on the order of 2500 psi. It is highly probably, if not certain, that the 2500 psi of pressure on that reservoir will replenish water much faster to the reservoir than we can pump it down.

## SUMMARIES OF THE GEOLOGICAL ISSUES

Joseph Halbig  
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As I see it there are three geological concerns in the Puna area. These three broad concerns involve first the gaseous effluents, then the liquid effluents, and finally, ground deformation. Charlie Lamoureux has talked a little bit about the gaseous effluents and the effects they might have on surface vegetation. The way I see it the component which is of greatest concern is the hydrogen sulfide gas. There will be a scrubbing system for the extraction of  $H_2S$  which will probably be on the order of 90 to 95% efficient, which means that the amount of  $H_2S$  and sulfur oxides that may be emitted may be on the order of 20 to 40 ppm.<sup>2</sup> Certainly in the near vicinity of the well this would be considered a nuisance odor, and depending on the meteorological conditions, it may be a nuisance to the surrounding communities. The other thing that is important to consider are the long term effects of the gaseous effluent on the vegetation in the surrounding area. It's true that the ambient levels of some of these things are small at any distance from the well, but the long term effects are very difficult to determine. I think that's something that should be looked at very critically.

The second effluent that will be expelled in the gaseous form will be water, and Charlie has talked a little bit about that as well, the effect that an increase in the moisture regime will have on the vegetation. I think that's something that should be looked at.

Going on to the liquid effluent, the Puna area has no permanent streams, so I don't think we have to worry about contamination of stream systems or surface water. If the effluent was put into a channelway, certainly it would soak into the ground in short order, so I don't think there is any possibility of stream contamination. However, certainly there will be some contamination in the near vicinity of the pool or pond, and what effect this will have on the groundwaters in the area is hard to ascertain. Certainly there will be a pollution plume which enters the groundwater, due to the fact that the material percolates through the bottom of the pond. What the extent of this pollution plume will be in the groundwater system is something that ought to be looked at by means of observation wells in the area and other types of monitoring devices.

If the groundwater flow is uniform, then you would expect to get a more or less isotropically shaped plume which comes out from the area; however, you can expect at depth that, particularly in this area, there are a lot of subsurface fractures and cracks, lava tubes, and this could provide for the pollution of groundwater in a nonuniform manner. In other words, the groundwater could travel for considerable distances and still retain fairly high concentrations of the material which is contained in it. The waters will be acid, because the  $H_2S$  which is being scrubbed out is being absorbed as sulfur dioxide in the water, so there will be an acid effluent that gets into the groundwater.

The third geologic concern of the area is the concern with ground deformation. This has been looked at pretty carefully in the planning of the geothermal facility. Certainly, this is a very active area, located right on the flank of the east rift zone. The things that would have to be looked at would be ground subsidence, maybe an increase in seismicity in the area, and in other geothermal areas this has been noted to occur. The USGS has done studies in the

Geysers area and there have been small amounts of ground subsidence, small amounts of horizontal movement, small increases in microseismic events, but nothing really large. I doubt if there would be anything large enough to worry about here. The reservoir rock we have here in the Puna District is pretty deep, and I doubt if there would be any effect on ground subsidence resulting from fault movement in the immediate area where the plant is, as a result of drawdown of fluid from the well. Most of the subsidence, as a matter of practice, that you might expect in the area would be due to inflation rather than to a decrease in pore pressure caused by the well.

Probably of the three aspects that I have talked about, the subsidence and increased seismicity would be of least importance. I think they are the three main things involved in the geological aspects of the well site.

#### QUESTIONS AND COMMENTS

Q. (from Bill Chen) The three things you have mentioned are certainly things that we realize, so we have a rather extensive monitoring program. For  $H_2S$  we have three continuous monitoring stations: one at the emission point, one at the property line, and one at the nearest residence. We also will have portable, disposable systems that will be placed at strategic positions, depending on the weather conditions. So I think  $H_2S$  is being monitored very closely, and all the instruments can go down to 30 parts per billion. For liquid effluents, we have five wells and streams and we will be monitoring a year ahead of time and for 2 years during the operation to see what we have in the disposal waters. For subsidence and seismicity, for one thing, the bottom porosity varies between 3 and 18%, so the possibility of subsidence is fairly small, but we do have detection equipment set up by the HIG people and a few other people. Probably anything that occurs will be due to volcanic activity, but we will be monitoring it.

Q. You, Dr. Howard, and a number of people in the citizens' groups have mentioned lava tubes. How much do we really know about them on this island? Where they are, how extensive, what's in them...

A. I don't think there's really been a survey done. I don't know of any in the Puna District to see what the subsurface structure looks like. If you go to any great depth you wouldn't expect tubes, since they are a low pressure feature. The tubes that you get will be fairly shallow; however, that would influence considerations of ground water pollution.

A. (Bill Chen) The first 1700 feet were surface lavas when we drilled; below 1700 feet were all pillow lavas and very dense material. We have drilled some pilot holes for construction, and there are some lava tubes below. We expected to find lava tubes, and that's one of the things we always do here, is drill pilot holes for construction. But it's still a very good base.

A. (Don Thomas) When the well was being drilled, the people who were watching the drill bit as they drilled down through the rock said that they would be drilling through very hard rock and the bit would then drop four feet. They assume that they struck lava tubes. Another indication that the lava tube network in there is quite extensive is that the circulation in the well (when they drill, drilling mud is pumped down the well to pump the chips back out) was maintained with a great deal of difficulty, because the lava tube system down



there was so extensive that everything pumped into the well "went away"; they never saw it again. In fact it created quite a substantial difficulty in drilling the well, because the expense of continually pouring mud in there couldn't be maintained. They were pouring bagasse, cotton seed hulls, anything they could think of down into the well to try to plug it up. So as far as lava tubes are concerned in that area, they are probably all over the place.

Q. I was asked a question this morning by a number of people who have homes that sit on lava tubes, and they were very much concerned with microearthquakes or very small levels of subsidence, enough to collapse a few lava tubes that perhaps are under their houses. What are the chances of this happening?

A. I don't think there would be any connection.

One thing I wanted to mention earlier was about the heavy metal content, which is seemingly low. There is some mercury in the well, and I think one consideration is not only that the mercury content is low, but what other elements are present along with the mercury. The effluent does have quite a bit of chloride in it. It's well known that the presence of mercury in a chloride environment increases its mobility considerably, particularly if such things as methylated mercury chloride are produced. I know the mercury content is low, but I think this is another thing that has to be considered as far as long term effects in the area, particularly since you have the chloride present.

Q. When you talk about the effects of mercury in the area, the question in my mind is, by comparison with the mercury budget that's being added to the area by Kilauea, it would seem that anything you do at the Puna well has got to be trivial compared to that.

A. Except that the mercury that's being emitted in the Kilauea area does not have associated with it the chloride to the extent that the effluent does at the geothermal well. And the chloride tends to increase the mobility of the mercury through biological systems.

Q. Will this geothermal development lessen the volcanic activity up at Kilauea?

A. I doubt if it will. I don't think there will be any effect at all on the volcanic system up in the Kilauea area.